THE MOON-ELEMENT

THE EXPLORING OPTOPHONE, 1912.

Mr. Arthur Burrows lets a blind man hear the light of a match. Author on left.

[*Frontispiece*

THE MOON-ELEMENT

AN INTRODUCTION TO THE WONDERS OF SELENIUM

By
E. E. FOURNIER D'ALBE, D.SC., F.INST.P.

T. FISHER UNWIN LTD
LONDON: ADELPHI TERRACE

First published 1924
Second Impression . . . 1925

TO

WESTGARTH FORSTER BROWN

PREFACE

In this book the reader will find the first connected account of the properties and applications of a chemical element which has raised—and disappointed—more hopes than any other element known. Selenium is now just coming into its own, and it promises to have a paramount influence upon wireless and other new developments of the present century. On the eve of the new year, Sir Oliver Lodge addressed a great meeting of wireless devotees. He concluded by saying:

"We are living in an extraordinary time. The first twenty-three years of this century have started out remarkably, and what may be going to come in the next twenty-three years during which you will live and work, who can say? I only know that the amount of things to be found out in the universe is enormous; more than what we have found out. We live in a most mysterious and wonderful time, and it is our privilege to find out and harness and use our discoveries for the benefit of man."

Sir Oliver Lodge was closely connected with at least one of the operations of selenium described in

this work, but few are the people who realise what it means to "harness our discoveries for the benefit of man," and how such harnessing may depend for its success upon the action of a few public-spirited people.

E. E. FOURNIER D'ALBE.

February, 1924.

CONTENTS

ILLUSTRATIONS

THE MOON-ELEMENT

CHAPTER I

ELECTRICITY AND LIGHT: A SKETCH OF MODERN KNOWLEDGE

THE mythology of Ancient Greece—that unsurpassed apotheosis of the human race—tells us that in the beginning there existed Uranos and Gæa, Heaven and Earth. From their mystic union sprang Hyperion, the Titan or super-man, the eternal rebel against Fate. And it was Hyperion who became the Father of Light. His beautiful children, Helios, the Sun; Selene, the Moon; and Eos, the Dawn, came to gladden the world for ever with their precious gifts of illumination.

It is fitting that the name of another great agent in natural phenomena should be derived from the Greek. Electricity is the amber-force, which to the Greek mind resided in that precious yellow jewel from the Baltic, more valuable than gold, which the Greeks called "Electron."

And these two great agents, Light and Electricity, are linked together by an element named after the

Shining One who, in her silver chariot drawn by white horses, drives nightly across the star-strewn heavens.

The beautiful fancies of Ancient Greece have faded away into the realm of the ideal before the dry light of modern science. And yet, who shall say that our present-day conceptions are more "real" and less fanciful than those of the Greeks? We speak of light as consisting of vibrations of an all-pervading yet intangible substance, a substance which has consistently eluded all our efforts to prove its actual existence. Like the Greek gods, the ether indicates its existence by its actions. Zeus reveals himself in his thunder, and the ether manifests itself in the vibrations which constitute light. The frontier between knowledge and imagination has not been pushed back very far!

The nature of electricity is, if anything, still more mysterious. We "know" by this time that it consists of two sorts of electric atoms, the "negative" ones being called "*electrons*," and the "positive" ones being called "*protons*." The electrons produce most of the electrical phenomena accessible to our senses. Present-day science is disposed to assume that all matter consists of different aggregations or arrangements of these protons and electrons, which play the part of the elementary particles called "atoms" by the great Greek philosopher Democritus. And so we arrive at the dictum that electricity is the basis of all matter. Such a dictum

removes the final mystery one stage farther back, and leaves us face to face with the question: What is Electricity? Whatever it may be, it presents a dualism such as confronts us in the organic world through the contrast between an active and mobile male sex and a passive, receptive, and more or less stationary female sex, the former being typical of the negative electrons and the latter of the positive protons. It would not be altogether surprising to find some audacious philosopher of the future describing the two kinds of electricity as consisting of living beings of sub-atomic dimensions, divided, like the higher animalcules, into two sexes, and living their life on a scale of time and space removed a millionfold from the latter. In that case the ultimate laws of nature would be laws of life instead of being laws of "dead matter," and a tremendous step would be achieved towards the unification of our philosophic conceptions.

But that time is not yet, and we must leave the elucidation of the ultimate nature of electricity to the future. We must take the proton and the electron for granted, and endeavour to account for electrical phenomena by their various combinations and relative displacements.

Ordinary matter we must imagine as consisting of protons and electrons in equal numbers. Any portion of matter containing an excess of protons will be "positively charged," and any portion of matter containing an excess of electrons will be "negatively

charged." Thus, if we rub a stick of sealing-wax on fur, the sealing-wax will deprive the fur of some of its electrons. The fur will be positive, and the sealing-wax will become negatively charged. The two oppositely charged bodies will attract each other, as do the protons and electrons themselves. The hairs of the fur will point towards the sealing-wax.

Could we but enlarge a piece of the sealing-wax a hundred millionfold, we should see a structure of indescribable grandeur and beauty. We should see untold numbers of three-sided pyramids—the carbon atoms—interspersed with hydrogen atoms, each consisting of one proton accompanied by one electron revolving round it, like a planet round the sun. Then there would be the nitrogen atoms, each containing fourteen protons, nine of which are locked up in the centre with nine electrons to match them, while the other protons and electrons are more or less loosely attached to the triangular nucleus. The oxygen atoms would look like octahedral diamonds. Then there would be the more complicated mercury and sulphur atoms constituting the vermilion which gives the sealing-wax its red colour. All this array of atoms would be seen arranged in groups and subgroups and larger aggregations, and in and out among them would be seen to dart a few free electrons, ready to follow any electric forces acting from outside, and constituting what little "electric conductivity" is possessed by a high insulator like sealing-wax.

Waves of light, some fifty thousand of which go to the inch, would appear very large compared with the atoms constituting the sealing-wax, and would, in fact, surpass the diameter of atoms several thousand times. It is only when we come to ether waves of the shortest length, those known as X-rays and Gamma-rays respectively, that we find anything like the small dimensions of the atoms themselves.

The late Lord Kelvin used to illustrate the size of atoms, or rather of those simple combinations of different atoms called "molecules," by saying that if a drop of water were magnified to the size of the earth, the molecules of the water would appear as large as cricket balls. They would be sufficiently far apart to move about freely, like a loosely packed crowd. But the molecules would not in the least resemble cricket balls in appearance. They would appear as clusters of atoms, and each atom would be a sort of solar system consisting of a closely packed nucleus surrounded by revolving electrons. The latter would fill up no more space within the "atom" than do the planets, comparatively speaking, in the solar system of our sun. If the atom were the size of a cricket ball, the electrons would be smaller than pins' heads. But small as they are, they are packed with material of what is to us an inconceivable density, so that their mass-effect is quite considerable—so considerable, in fact, that they are capable of melting platinum by the force of their impact. The electron

in motion is the most terribly effective projectile known.

Let us endeavour to form a mental image of the forms of matter as we know them, enlarged sufficiently to show their atomic structure. The simplest form of matter will be a gas, say oxygen or nitrogen, or that mixture of both which we call Air. Let us enlarge the sample of air so that its new diameter is one hundred million times its former diameter, and let us, at the same time, reduce the tremendous speeds of atoms and electrons in the same proportion. Then what shall we find ?

Each molecule of air will be about an inch across. It will be a sort of twin star, consisting of two atoms with their attendant electrons. The molecules will be some 10 inches apart on the average, but they will be found to be in constant motion, like a swarm of midges, covering about half an inch per hour on the average. Each molecule will move in a straight line until it encounters another molecule. It will do this after traversing, on the average, a distance of 30 feet, so that each molecule will collide with another about once per week. Such a collision will disturb the equilibrium of both molecules, and it will happen occasionally that an electron will leave one molecule and take up a temporary abode with the other. This is not surprising if we consider that the (new) speed of the outermost electrons will be about half an inch per second, or about a

thousand times greater than the speed of the molecules.

When such an exchange of electrons takes place, the molecules will no longer be electrically neutral, but will be "electrically charged." The molecule which has lost an electron will have a "positive charge," while the molecule which has captured it will have a "negative charge." These charges force the two molecules (which are now called "ions") to obey any electric force which may be acting upon the gas from outside. The gas becomes to some extent "ionised," or converted into "ions." (We shall see later how light ionises selenium.) In time, all the molecules of the gas would be ionised by collision, but for the fact that the two sorts of ions attract each other and approach sufficiently to allow the errant electron to return to its former allegiance. In the long run, a state of equilibrium is attained, in which there is a permanent residue of ions in a large volume of gas.

Now let us imagine the gas condensed into a liquid. The molecules will be in actual contact, but it will be a loose contact which allows them to glide about among each other, like a sea-side crowd in a popular resort. The molecules will form larger aggregations, and if there are any strange molecules among them, or powerful ions, each of these will collect round it, or drag about with it, a retinue of neutral molecules, much as a show or a procession does in a crowd. If

an electric force acts upon the liquid from outside, a migration of the ions will set in. They will slowly drag themselves through the jostling crowd of molecules in obedience to the call, and will communicate their charges to the metallic " electrodes " from which the force is exerted. We shall have, in fact, what is known as " electrolysis."

Finally, let us consider the molecules condensed into a solid. As most ordinary gases are difficult to solidify, we must imagine the solid compound of other atoms, say those of copper or sulphur. Those of copper will each contain twice as many protons and electrons as those of sulphur, and each copper atom will therefore weigh as much as two sulphur atoms. But in addition to this, the copper atoms will be more closely packed, so that a given volume of copper contains more than twice as many copper atoms as the same volume of sulphur contains of sulphur atoms. It is, therefore, not surprising that the electrons which are loosely associated with the copper atoms—those which revolve in the outer orbits of the atom—are comparatively easily detached and allowed to roam freely through the substance of the copper. The atom of sulphur, on the other hand, is so constituted that it can absorb one or two extra electrons with comparative ease and keep them in a state of permanent attachment. And so we find that while a lump of copper contains very many unattached electrons, a lump of sulphur contains

very few indeed. In other words, copper is a "good conductor" of electricity, while sulphur is a very bad one—in other words, it is an excellent "insulator."

If we rub the lump of sulphur with wool or fur, it will absorb electrons from them, and will thus become "negatively charged." The fur, having lost electrons, will become "positively charged." Now let us separate the fur from the sulphur and place

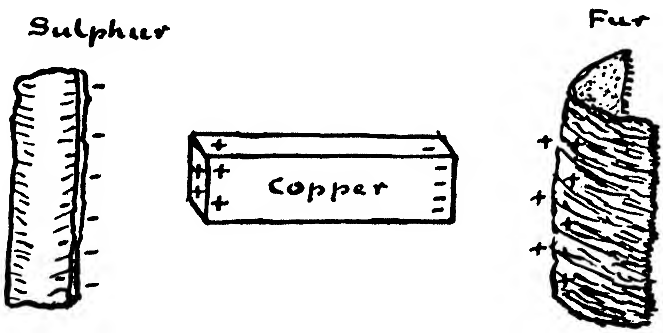

FIG. 1.—CHARGING BY INDUCTION.

between them our lump of copper. The free electrons, being repelled by all other electrons, will tend to move away from the "negative charge" of the sulphur, and will be attracted by the "positive charge" (the unbalanced protons) of the fur. One end of the copper will thus acquire a negative charge, while the other end—the end from which the electrons have fled—will be "positively charged." This process is known as "charge by induction."

It would be quite feasible to divide the copper in

the middle, and so obtain two pieces, one being "negatively" and the other "positively" charged. If we then remove the sulphur and the fur, the electrons in the "negative" copper will tend to return to their natural allegiance and alliance with the unmatched protons in the "positive" copper. They find it, however, very difficult to emerge from copper unless it is heated to a red heat, and so they will take up their positions as near to the "positive" copper as they can. Such a combination of two oppositely charged conductors is called a "condenser," because it allows us to accumulate a considerable electric charge and to store it for some time. It can be liberated by separating the two conductors. If we thus take the piece of copper containing the supernumerary electrons and let it touch an uncharged piece of copper, the free electrons will distribute themselves over the two pieces. The new piece will thus be "charged by contact." It can be discharged by allowing it to touch a large conductor, which will deprive it of most of its spare electrons.

Such, briefly, is the modern view of what has been known for a century as "electrostatic" charge. What is the corresponding view of an electric current?

Imagine a row of copper balls placed close together. Charge the first of them by contact and let it share its electronic charge with the next. Let the latter share its charge with the next until some of the spare electrons are distributed over the whole row. Then

it is obvious that there has been a procession of electrons from the first to the last ball. On joining the last ball to a water pipe it will lose all its spare electrons, and if all the balls are in contact the whole battalion of unattached electrons will pass into the earth.

Now it is quite feasible to repeat this process indefinitely, so that there is a steady flow of electrons through the metal to the earth. *That flow constitutes an electric current.* All currents in metals are but a procession of electrons wending their way through the crowds of atoms, knocking up against them, being absorbed and again set free, but continuing steadily towards the goal set for them by the electric field of force in which they are placed.

The flow will be the more copious the greater the number of free electrons. That is why it is more copious in copper than in most other metals, and why it is so very meagre in sulphur and other insulators. It will also be greater—the current will be "stronger"—the more rapidly and smoothly the electrons can proceed on their way. If there is no obstacle at all (in a vacuum, for instance), a thin stream of electrons flowing at a great rate may constitute quite a considerable current. But any opposition encountered by the electrons increases the "resistance" of the substance, and the resistance can be measured by the heat evolved by the stoppages and collisions. If, in spite of the resistance, we force up the current until it is doubled, not only will the number of electrons

traversing the conductor in a given time be doubled, but the rate at which each electron does its work in overcoming resistance will be doubled also. Thus the amount of heat developed will be increased fourfold.

We may put these rules concisely into words as follows: (1) The current is proportional to the electric force ("electromotive force," "E.M.F.," or voltage) and to the conductivity (Ohm's Law). (2) The heating effect is proportional to the square of the current (Joule's Law).

There is a fundamental law of motion, first formulated by Newton, and called Newton's Third Law. It maintains that "Action and Reaction are always equal and opposite." In other words, if a body is set in motion by a force acting between it and another body, the amount of motion, or rather "momentum" (mass multiplied by speed), in both directions is equal. We cannot jump off the ground without pushing the earth away from us by a certain amount —an infinitesimal amount, indeed, but for all that an amount suitable to the disproportion between our own mass and that of the Earth.

A somewhat similar thing happens in the domain of electricity. We cannot set electricity in motion, nor can we start a body of ions or electrons in any direction, without starting other electrons in the opposite direction. It is just as if every electron were connected with every other by invisible elastic fibres, so that none of them could start in any direction

without the help of all the rest. Supposing we had a rod of copper containing an excess of electrons, and that we suddenly moved it in the direction of its length. Then in any neighbouring copper rod parallel to it electrons would start in the opposite direction. This flow would, however, only proceed so long as the speed of the charged rod was increasing. A uniform displacement produces no effect. On stopping the charged rod, the electrons in the other would rush forward into their former places. This phenomenon is known as electromagnetic induction or current induction. We can, in fact, temporarily "induce" a current in a coil of wire by starting or stopping a current in a neighbouring coil. The closer the neighbourhood, the stronger will be the effect, so that we can produce an induction effect by merely bringing a coil bearing a steady current near another coil at rest, or removing it away from it. If two wires or coils bearing currents in the same direction are brought close to each other, they will mutually reduce their currents during approach, and increase them during removal.

There is a certain inertia or persistence which opposes the starting or stopping of a current in a conductor, quite apart from the "resistance" of the conductor to a steady current. This inertia recalls Newton's First Law of Motion, according to which a body, once started, tends to proceed uniformly in a straight line unless and until it is stopped or deviated by a force applied to it.

The induction of currents is but an illustration of this general law. For if, in order to start a current in one conductor, we must start other currents in all neighbouring conductors, the work of starting must be considerably increased. This difficulty is also presented by the turns of a single coil, each turn acting as a drag upon its neighbours. Such a form of electric inertia is called self-induction or simply "inductance"—a term with which all wireless devotees are familiar.

The influences thus exerted "across space" are not propagated instantaneously, but with a limited though very great speed, and this fact irresistibly suggests that there must be a medium through which they are propagated, a medium whose properties determine that speed of propagation. This hypothetical medium is called "the ether of space." Every movement of an electric charge, whether it consists of electrons, protons, larger ions, or charged bodies, sets up some sort of "strain" in the ether, which is propagated in all directions with the speed of light. It is this strain which is supposed to produce those movements of electricity in neighbouring conductors which we call induced currents. It is also manifested in the forces acting between conductors which are already conveying currents. These forces always act in the sense of placing the currents so that they are parallel and in the same direction ("electrodynamic action"). The most remarkable instance of this action is the magnetisation of a piece of soft

iron by a current traversing a coil wrapped round the iron, as in an electric bell.

What happens in this case may be described as follows. The atoms of the iron, like all other atoms, have a number of electrons revolving round their nuclei in circular or elliptical orbits. But in iron these orbits are more or less in one plane, like the orbits of the planets of our solar system. Now when a current circulates in the wire round the iron, all these electronic orbits tend to set themselves in such a manner that their electrons circulate in the same sense as the electrons in the wire. When that happens, the iron is said to be "magnetised." What we call magnetism is, in fact, nothing but the action of the tiny atomic currents upon each other or upon currents in ordinary conductors in obedience to the laws of electrodynamic action. *Every electron or other electric charge in motion exerts magnetic force,* and the electrons revolving in atomic orbits are no exception to this rule.

When, instead of the steady rotation of electric charges, we have their starting and stopping, their acceleration and retardation, their surging up and down or to and fro, we get, not magnetism, but radiation. Electromagnetic waves are produced in the ether, and are propagated through space with the velocity of light. The speed of light, being 300,000 kilometres (186,000 miles) per second, it is easy to calculate the length of these waves if we know the frequency with which the surgings at the

source take place. If there is one to-and-fro movement per second—which might be produced by separating the two charged pieces of copper (p. 21) and approaching them again—the length of the wave will be 300,000 kilometres. With a frequency of a million per second we should get a wave-length of 300 metres, which is not far from the wave-lengths currently used for "broadcasting." Increasing the frequency another millionfold, we should get a wave-length of one-thirty-third of a centimetre, or small waves eighty-four of which would go to the inch. We should have to increase the frequency another five hundred times to produce light-waves. We should then have red light, with waves so short that forty-two thousand of them went to the inch.

We cannot, of course, produce several billion electric displacements per second mechanically. Nor is it, indeed, known as yet how they are produced in nature. The sun and other sources of light produce them in abundance, and it was thought for some time that we must seek their origin in those atomic circuits or electronic orbits which determine the phenomena of magnetism. But a magnet does not radiate light, whereas all ordinary bodies when raised to a certain high temperature do. The theory of radiation is just at present in one of those critical stages which often precedes discoveries of far-reaching importance. It is safe to say, however, that an atom does not radiate light except in a certain state of transition from one state of equilibrium to another.

It may be that an electronic orbit breaks down, as cometary orbits sometimes do, and the electron finds another orbit nearer the nucleus. While passing from one to the other, the electron sends out its S.O.S. message as a thrill through the ether of space, and we receive it as a flash of light.

Another peculiarity of light radiation which is now definitely established is that it is transferred in definite quantities or "quanta." Each quantum or parcel of light is the greater the more rapid the vibration.[1]

There is probably some connection between this peculiar law and the position of the electronic orbits in the atom. Just as in the solar system, the inner electrons—veritable planets revolving round the central nucleus—have much shorter periods than the outer ones. They are also in a more intense field of force, and any change probably takes place with explosive violence. Hence it is the high-frequency radiations which have the greatest intensity.

Our eyes are sensitive to but a very limited range of electric waves. There are waves flooding space—waves of invisible light—which our eyes are unable to perceive. The sun sends out waves longer than those of red light. We can only perceive them through our sense of heat. It also emits waves shorter than those of violet light. We call them

[1] This is Planck's "quantum," the value of which is $n \times 6{\cdot}55 \times 10^{-27}$ *erg* for a frequency of n vibrations per second. For the brightest sunlight the quantum is 3·8 billionths of an erg.

ultra-violet, and receive them on photographic plates, which are very sensitive to them. The ear is sensitive to ten or eleven octaves of the scale of notes. The eye does not cover even one octave of light waves. But it is a marvellous instrument all the same, consisting of a hundred million separate receivers distributed over the sensitive surface called the retina. These receivers are affected by light in a chemical sense, a delicate substance called the "visual purple" being decomposed by light and rapidly re-formed in darkness. Many ocular phenomena, such as blinding or dazzling, fatigue, and after-effect, are shown, as we shall see later, by selenium in much the same manner as in the eye.

Photography has familiarised us with the chemical possibilities of light. The action of selenium will show us its electrical possibilities.

Many things may happen to a beam of light once it has left its source. It may fall upon a polished surface and be reflected, much as a sea-wave is reflected from a sea-wall. It may be absorbed and converted into heat, like breakers on a pebbly beach. It may pass freely through the substance, undergoing some change of direction in transmission owing to the influence of the electrons bound up with the atoms of the transparent body.

If it is absorbed it may do many different things. Absorbed by the eye, it produces the sensation of light. Absorbed by a green leaf, it evolves oxygen. Absorbed by a photographic plate, it reduces the

silver bromide and produces a latent image. Absorbed in large quantities by the skin, it darkens it until, in the course of many generations, it produces the Black Man. Absorbed by zinc or colloidal potassium charged with an excess of electrons, it enables those electrons to emerge into open space, and gives rise to "photo-electricity."

Absorbed by crystalline selenium, it produces in it those temporary and significant changes which it is the purpose of this work to describe and investigate.

CHAPTER II

DATES AND DATA CONCERNING SELENIUM AND SELENIUM CELLS

THE discoverer of selenium, Jöns Jakob Berzelius, who was professor of chemistry at Stockholm and Secretary of the Swedish Academy of Sciences, gave the following account of his discovery:

"This body was discovered in 1817 in the following manner: I was examining, together with J. G. Gahn, the method formerly in use at Gripsholm for preparing sulphuric acid. We found in that acid a sediment, partly red and partly light brown, which before the blow-pipe gave an odour of rotten radish and left a grain of lead. That odour had been described by Klaproth as indicating the presence of tellurium. Gahn remembered that he had often noticed the smell of tellurium in places where the copper ore of Fahlun was worked, yielding the sulphur employed in the manufacture of the acid. The hope of finding such a rare metal in this brown sediment induced me to examine it. In undertaking this research, my only object was to separate the tellurium, but I found it impossible to discover that body in the material I examined. I therefore caused the whole of the sulphuric acid deposits to be collected, using nothing but Fahlun sulphur, and after collecting a large quantity I examined it in detail. I then discovered an unknown substance with properties

closely resembling those of tellurium. This resemblance induced me to call it Selenium, from the Greek word Σελήνη, which signifies the Moon, while *Tellus* is the name of our own planet."

For over fifty years the new element remained little but a chemical curiosity. It was found that its atom weighed 79·2 times as much as the hydrogen atom, that it melted at 217° Centigrade and boiled at 690°; that it occurred in several "allotropic" modifications, the lightest of which weighed 4·3 times its own bulk of water; that it was insoluble in water, but dissolved readily in acetone, aniline, and other organic liquids; that it was allied to sulphur, a non-metal, on the one hand, and to tellurium, a metal, on the other, being itself practically non-metallic; that it occurred, combined with sulphur, in Swedish pyrites; that, when burned in air, it gave off an unpleasant smell of rotten horse-radish, and formed a white oxide, which in water became selenious acid (SeH_2O_3); that with chlorine it formed a brown oily liquid capable of dissolving crystallised selenium.

But none of these properties were of any interest outside a text-book of chemistry. The great property of selenium, that of becoming a conductor of electricity when illuminated, was not discovered until 1873. The discovery was made at the Transatlantic Cable Station on Valentia Island, off the coast of Kerry, in the course of some experiments in cable signalling for submarine telegraphy.

Here follows the full account of this momentous

discovery, as given in a communication made by Mr. Willoughby Smith, Electrician of the Telegraph Construction Company, to the Society of Telegraph Engineers in London on February 12, 1873. The communication was presented by Mr. Latimer Clark, and was first published in *Nature* of February 20, 1873:

"Being desirous of obtaining a more suitable high resistance for use at the Shore Station in connection with my system of testing and signalling during the submersion of long submarine cables, I was induced to experiment with bars of selenium, a known metal of very high resistance. I obtained several bars varying in length from 5 to 10 centimetres, and of a diameter of 1 to 1½ millimetres. Each bar was hermetically sealed in a glass tube, and a platinum wire projected from each end for the purpose of connection.

"The early experiments did not place the selenium in a very favourable light, for the purpose required, for although the resistance was all that could be desired—some of the bars giving 1,400 megohms absolute—yet there was a great discrepancy in the tests, and seldom did different operators obtain the same result. While investigating the cause of such great differences in the resistance of the bars, it was found that the resistance altered materially according to the intensity of light to which it was subjected. When the bars were fixed in a box with a sliding cover, so as to exclude all light, their resistance was at its highest, and remained very constant, fulfilling all the conditions necessary to my requirements; but immediately the cover of the box was removed, the conductivity increased from 15 to 100 per cent. according to the intensity of the light falling on the

bar. Merely intercepting the light by passing the hand before an ordinary gas burner placed several feet from the bar increased the resistance from 15 to 20 per cent. If the light be intercepted by rocksalt or by glass of various colours, the resistance varies according to the amount of light passing through the glass.

"To ensure that temperature was in no way affecting the experiments, one of the bars was placed in a trough of water so that there was about an inch of water for the light to pass through, but the results were the same; and when a strong light from the ignition of a narrow band of magnesium was held about nine inches above the water the resistance immediately fell more than two-thirds, returning to its normal condition immediately the light was extinguished."

The announcement created a great stir among physicists and electricians. It also evoked criticism along the customary lines. Such criticism usually takes three forms: (1) That the phenomena alleged are due to some other cause; (2) that they are not new; and (3) that if both new and true, they are of no possible use to anybody. One well-known chemist wrote to *Nature* to say that he had attempted to repeat Willoughby Smith's experiment, but had not only been unsuccessful in obtaining his result, but had not succeeded in getting a current to pass through selenium at all. A German chemist did obtain an effect of light on selenium, but went to the other extreme and claimed to have proved that sensitiveness to light was also exhibited by silver, gold, and

indeed all other metals. But the truth did not take long in getting firmly established. Professor (afterwards Sir) Norman Lockyer, the Editor of *Nature*, caused selenium to be studied by Commander Sale, R.N., who reported that thin slabs of selenium were sensitive to all the colours of the spectrum, but more especially to the visible red. Further investigations by W. Grylls Adams in England and W. Siemens in Germany fully confirmed the remarkable discovery, and from that day to this there has been a never-ending stream of contributions to the study of the Moon-element, an element as fascinating as any of the ninety-two elements in Nature's catalogue, and far more elusive than most.

The development of our knowledge concerning selenium may be gathered from the following chronological table :

1817. Berzelius discovers selenium.
1845. Riess determines its electrical conductivity.
1851. Hittorf discovers allotropic forms of selenium.
1856. Regnault determines specific heat of selenium.
1858. Matthiessen determines voltaic power of selenium.
1869. Fizeau determines thermal expansion of selenium.
1873. Willoughby Smith discovers the sensitiveness of selenium to light.
1874. Quincke determines the refraction and absorption coefficients of selenium.
1875. Siemens proposes a selenium photometer.
1878. Sabine constructs electrolytic selenium cells.
1880. Graham Bell invents the photophone.

1880. Perry and Ayrton propose electric vision.
1881. Shelford Bidwell constructs new selenium cells.
1881. Kalischer and Mercadier construct photophones.
1883. Hesehus determines laws of action of light.
1891–93. Minchin uses selenium cells for stellar photometry.
1896. Giltay discovers action of Roentgen rays on selenium.
1901. Ruhmer transmits speech by means of the Speaking Arc. Invents the Photographophone. Transmits pictures.
1902. Korn improves picture telegraphy with selenium. Ruhmer constructs cylindrical selenium cells.
1905. Wulf and Lucas use selenium for the study of a solar eclipse.
1907. Korn transmits pictures from Munich to Berlin.
1908. Ries discovers anomalous actions in selenium.
1910. Ries suggests dissociation of selenium by light.
1912. Fournier d'Albe constructs first optophone.
1913. Fournier d'Albe constructs the first reading optophone.
1914. Fournier d'Albe invents the type-reading optophone.
1915. F. C. Browne invents the phonoptikon.
1916. A. O. Rankine invents the grid photophone.
1917. H. Grindell Matthews steers boat from shore by searchlight.
1918. First public reading demonstration with the optophone.
1920. " Black-sounding " optophone constructed by Barr and Stroud.
1921. Talking Films (De Forest, Rankine, Matthews, and others).

Physical and Chemical Properties of Selenium

Atomic Weight	79·2.
Linear Expansion per degree C.	0·000049 (crystalline). 0·000037 (vitreous).
Density	4·26 (red amorphous). 4·28 (vitreous). 4·47 (red crystalline). 4·80 (grey crystalline).
Melting Point	217° C.
Boiling Point	690° C.
Specific Heat	0·084 (crystalline). 0·095 (amorphous).
Specific Resistance (of cm. cube)	70,000 ohms (crystalline).

Construction of Selenium Cells

W. Siemens was the first to construct a "selenium cell" (1876). It consisted of two platinum wires wound in a flat double spiral and attached to a sheet of mica. The sheet and wires were then coated with molten selenium and exposed for some hours to a temperature of 200° C.

Many different forms of selenium "cells" have been devised since that time. The object of all designers was to reduce the resistance as much as possible. For the current obtainable from a battery discharged through a slab of selenium was always excessively small. It was therefore necessary to widen the path of the electrons through the selenium and also to shorten it as much as possible. A wire of crystalline selenium offers an enormous resistance —thousands of megohms—to the passage of a current.

If the wire were made very thick the resistance would be less, as many electrons could pass along abreast of each other. If the wire were made short as well as thick, the conditions would be still better. But another requisite is that the whole of the selenium should be capable of exposure to light. This can only be secured by spreading it in a thin sheet. If two parallel wires were stretched out close together we could send a current from one wire across to the other over a narrow obstacle of selenium filling up the gap between the two. If, in addition, we roll the parallel wires up in a flat spiral, we obtain the Siemens cell described above.

Bidwell (1880) devised a more convenient form of cell by cutting a series of notches in a square of slate and winding two wires in a spiral round them.

Graham Bell (1880) used a brass plate perforated with numerous holes which were nearly plugged by corresponding cones attached to a second plate. The interstices were filled up with selenium. A better plan of the same inventor was to make cylindrical selenium cells by building up a cylinder consisting of numerous circular brass plates separated by discs of mica of a slightly smaller diameter. The remaining interstices were filled up with selenium and alternate brass plates were connected together to form the two electrodes.

Mercadier (1881) rolled up two narrow strips of thin brass, separated from each other by means of

parchment, into a spiral and covered one face of the spiral with selenium.

Fritts (1883) had the novel idea of coating two glass plates with gold-leaf, pressing molten selenium into a thin layer between them, and illuminating the latter through the semi-transparent gold.

Righi (1888) also used selenium discs, but pressed them between wire gauze.

Liesegang (1890) produced a very simple cell by ruling a line across a thin layer of silver on glass and filling up the gap with selenium.

Ruhmer (1902) produced cylindrical selenium cells by winding a double screw thread on a cylinder of steatite, which was wound with wire and then coated with selenium.

Quite a new form of selenium cell was invented by Sabine in 1878. He coated a metallic plate with selenium on one side, while varnishing the other, and placed it opposite another plate in an electrolyte. On illumination this "electrolytic selenium cell" was found to produce its own electromotive force. Minchin (1895) improved this type by coating the flat end of an aluminium wire with selenium, enclosing it in a glass tube open at both ends and immersing it in a solution of œnanthol opposite a platinum wire. This cell also produced an electromotive force under the action of light, and was used for star photometry.

All selenium cells made with wires wound close together suffer from a serious defect. It is the danger that a small portion of selenium between two wires

may melt with the heat of the current, whereupon the two wires are likely to touch and produce a short-circuit, fatal to any delicate instruments which may be connected with the cell. This danger is avoided in a cell devised by Presser, who covered a circular slab of soapstone with platinum and ruled concentric grooves in it, subsequently covering the entire surface

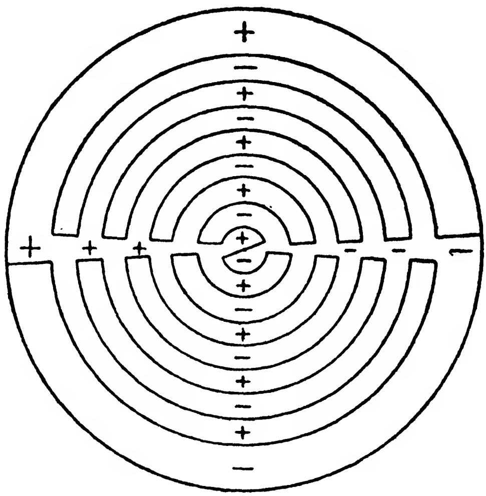

FIG. 2.—PRESSER CELL.

with a thin layer of selenium. The burning out of a portion of the selenium then only produces a slight increase in the resistance.

It is best, however, that no metallic substances be used to make the connection with the sensitised selenium, as all metals form selenides or compounds with selenium, and these compounds gradually reduce the sensitiveness.

Carbon forms no such compounds, and it can be very conveniently used in the form of graphite.

The best basis is unglazed "biscuit," sometimes called unglazed porcelain. But soapstone or slate can also be used.

The practical method of constructing carbon-selenium tablets, as worked out by the author, is as follows:

Cut out with a hacksaw a piece of ordinary writing

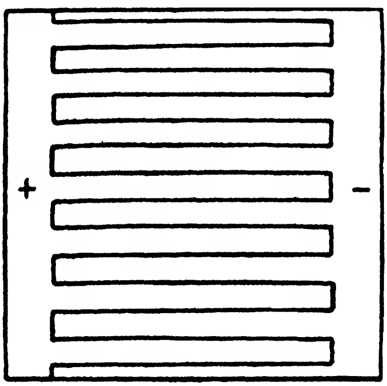

FIG. 3.—CARBON-SELENIUM TABLET.

slate of the size required—say, 2 inches square One surface should be smoothed by means of sand-paper. (If two pieces of slate are prepared, the two surfaces should adhere for a short time if pressed together.)

Now cover the smooth surface with graphite by rubbing it over with a soft pencil. After a good covering is attained, rub in the graphite with a piece of leather and produce a good black polish.

Next, inscribe a to-and-fro line in the graphited surface with a sharp steel point, cutting just sufficiently deep to penetrate the graphite surface. The cut (Fig. 3) should not be more than half a millimetre wide (about $\frac{1}{50}$ in.).

Now comes the more difficult operation—that of coating the surface with selenium.

As the fumes of selenium are unpleasant, the coating should be done in the open air or in a well-ventilated place.

Have ready two pairs of pliers, a Bunsen burner, a slab or block of iron, and a narrow strip of glass.

Light the burner, and grip one corner of the slate in a pair of pliers. Grip a piece of selenium about the size of a hazel nut in the other pliers. Plunge the slate into the flames, moving it to and fro so as to get an even heat. After half a minute or so the slate will crackle, without actually breaking. Whip it out of the flame and apply the selenium as if you wanted to paint it on. It will probably collect into drops. Apply a little more heat and you will find a temperature at which it spreads like butter, though it will then be too thick. Put down the selenium bit and take up the strip of glass. With this glass, spread the selenium evenly over the slate with the exception of the ungrooved portions at each side. The surplus selenium will adhere to the glass.

The above operation is difficult, but with some practice a smooth, even, glossy black covering of selenium can be obtained. Do not keep smoothing

after the selenium has begun to congeal, or you will get a purple crystalline variety which is quite insensitive.

After coating, the slate should be placed on the iron slab to cool quickly.

When cold, the selenium will be quite non-conducting. If a battery and a sensitive galvanometer are joined to the two uncoated side strips of graphite, no current should be indicated. If there is a current, it means that the grooving is incomplete at some

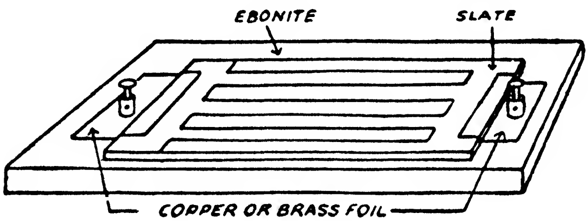

FIG. 4.—SELENIUM CELL WITH TERMINALS.

point. The zig-zag groove should be one continuous line dividing the graphited surface into two entirely separate portions.

If no current is indicated, we may proceed to "anneal" the selenium. This is conveniently done on an iron slab $\frac{1}{8}$ in. thick, heated with the Bunsen at one end. A steady gradient of heat can thus be obtained, one end being nearly red-hot while the other can still be touched.

The annealing consists of two operations. In the first operation the black lustrous selenium is converted into the grey crystalline variety by heating.

This consists in bringing the selenium gradually as closely as possible up to its melting point, and keeping it there for at least half an hour.

This can be done by putting it back on the former spot on the slab and gradually moving it up to the hot end.

Selenium melts at 217° C., and on cooling returns to the black, glassy, non-conducting state. Such melting must, therefore, be carefully avoided. While making the slate gradually hotter, watch for the appearance of black spots in the grey selenium. If you see one forming, whip off the slate on to the cold slab. The black spot will then often disappear by re-crystallising. In any case, you will know that you are sufficiently near the melting-point.

The final cooling on the cold slab must be accelerated by moving the slate about on the slab, as otherwise the selenium is likely to become "hygroscopic" and attract moisture.

As soon as the slate is cool, it is ready for mounting and testing. A simple mounting is shown in Fig. 4. The lightest contact between metal and graphite is as good as the heaviest, so long as it is secure. The metallic leads should not touch the selenium coating.

These graphite-selenium tablets have great stability, and some of them have been in use for many years without deterioration.

CHAPTER III

NATURE OF THE ACTION OF LIGHT ON SELENIUM

MANY different theories have been propounded in order to account for the action of light on the conductivity of selenium.

Moser (1881) supposed that the effect was due to heat, which improved the contact between the selenium and the electrodes of the cell.

Sale (1873) propounded the theory that the additional conductivity is due to ether waves penetrating between the selenium atoms and thus increasing the conductivity of the whole substance. In this case, of course, the effect should be instantaneous, which it is not.

Bidwell (1885, 1895) attributed the action to the formation of selenides with the material of the electrodes. This is refuted by the fact that carbon electrodes, which form no selenides, give equally good results.

Another hypothesis found many adherents. It is that there are two modifications of crystalline selenium, one of which is a good conductor, while the other is an inferior conductor. Ordinarily, these are in a state of equilibrium. But illumination upsets

this equilibrium, so that more of the highly conducting variety is formed. In the dark, this formation is gradually reversed, and the normal resistance is eventually re-established. This hypothesis was favoured by Siemens (1876), Berndt, Biltz (1904), Hesehus (1906), Pfund, Marc, and F. C. Browne. It is, however, rendered extremely improbable by the fact that most of the light-sensitiveness is retained at very low temperatures, such as the temperature of liquid air (– 185° C.), whereas chemical processes are either very much slowed down by extreme cold or stopped altogether.

Our views of conduction in solids have only become clear and definite since the new century began. We now know, thanks to the work of Sir J. J. Thomson, Riecke, Drude, Stark, and many other physicists, that metallic conduction consists in the conveyance of electrons through the metal, while the conduction of electricity through liquids means the passage of "ions" or groups of atoms, under the guidance of unbalanced electrons or protons, in the direction imposed by the electric field of force. In semiconductors like crystalline selenium we may suppose it to mean a mixture of both processes, but since even a prolonged exposure of selenium to a current shows little sign of the actual transfer of selenium atoms by the current, we can be pretty certain that what little electrical conductivity is possessed by selenium, or generated by light, is due to free electrons.

While in a lump of copper there are nearly as many free electrons as there are atoms, the case is very different in a poor conductor like selenium. We are not likely to be far wrong in estimating that there is normally only one free electron to every billion selenium atoms. A selenium tablet 1 inch square will contain about a million free electrons among its billion selenium atoms. When intensely illuminated, it will contain many additional free electrons, perhaps ten times as many as in the dark. In some selenium cells with large selenium crystals there may be a hundred times as many.

It is our business now to consider how light affects the number of free electrons. For the conductivity is directly proportional to it, and the whole value of selenium lies in the fact that we can make light impart an electrical conductivity to it.

It takes a certain effort to make an electron leave an atom with which it is bound up, in other words, to "ionise" the atom. This work is estimated to be about a ten thousand millionth of an "erg" (the physical unit of work). Now all light has a certain energy or capacity of doing work, and there is no reason why it should not perform the work of ionising the selenium atoms. A candle shining upon our selenium tablet from a distance of 3 feet would throw upon it sufficient energy to ionise as many as four hundred billion atoms per second, so that if the process went on unchecked for an hour the whole of the atoms of the selenium would be ionised

and it would acquire the conductivity of silver or copper.

That desirable consummation does not, however, take place. The conductivity of the selenium rises for a second or two, more and more slowly, and then reaches a value which remains constant for the rest of the time. On cutting off the light, the conductivity falls rapidly, though not so rapidly as it rose, and eventually returns to its normal value in the dark.

There is, therefore, some quality or agency which opposes the rise of conductivity, and which neutralises and annuls it at the first opportunity. So far from being fatal to the value of selenium, it is the most valuable quality of all. For a single and irreversible action of light would be nothing new. We have that at our disposal in the photographic plate. In the selenium cell we have an action which only subsists while the illumination is proceeding, and which ceases when darkness supervenes. We have, in fact, a performance which, more than the photographic camera, recalls the action of the human eye, which sees light only so long as it is there.

What happens when darkness comes? The answer is not far to seek, though it was sought in vain for thirty years after the discovery of the light-sensitiveness of selenium.

The electrons roaming about among the selenium atoms come across those among them which have been "ionised" and have thus lost electrons. That loss implies a "positive charge" of the rest of the

atom, and nothing is so effective in attracting an electron into an atomic system as the possession of a positive charge—an unmated proton, so to speak. So the wandering electron promptly "goes home" and the electric field is deprived of one more slave to do its bidding.

It is obvious that if there are many free electrons there will be many positively charged atoms, and the recombination of the ions will proceed more rapidly than if there are few.

A detailed study of the rate at which the ions recombine throws a flood of light on the process of ionisation by light. Such a detailed study was undertaken by the Author in 1913.[1]

It showed that the diminution of the number of ions due to light in the selenium was always proportional to the square of the number of ions there. This is just what we might expect. For if we were to double the number of ions of one kind (say electrons) we should double the chances of recombination in a given time. But if we double both kinds, the chances will be again doubled, so that on the whole they will be quadrupled.

Now we can see the reason why the conductivity of selenium does not at once return to its original value when the light is cut off. The free electrons produced by the light are at first very numerous, so that there are many chances of "mating" between

[1] "On the Efficiency of Selenium as a Detector of Light," *Proceedings of the Royal Society*, A., vol. lxxxix, p. 75, 1913.

electrons and protons, but as the reunited couples become more numerous, the unmated ions take longer to find their destined companions, so that complete reunion may require quite a long time.

Now let us consider what happens when we turn on the light. The waves of light fall on the sensitive surface and penetrate into it—not far, because crystalline selenium is an extraordinarily opaque substance. They churn up the atoms of the substance and shake out any loose electrons which may be on the verge of separation from their atoms. The number of electrons split off is *proportional to the intensity of the light.* This rule is again almost self-evident. For the "ionisation" of a single atom requires a definite amount of work, and the more energy enters the selenium, the more of that kind of work is done. It is the same in photography.

But now comes the important difference. The recombination of ions sets in with the same activity whether the selenium is illuminated or not. The rate of recombination is simply a matter of how many ions are present. Ionisation and recombination proceed simultaneously. But since recombination is proportional to the square of the number of ions present, it increases rapidly as ionisation proceeds. There soon will be a limit at which the number of ions formed by the light equals the number of ions recombined in the same time. The selenium will then have attained the maximum of conductivity possible for that particular intensity of illumination.

The energy of the light will then be proportional to the square of the number of ions formed. In other words, the number of new ions will be proportional to the *square root* of the luminous energy incident upon the selenium. In other words, the current due to the light will be *as the square root of the illumination.* This important law was actually found to hold good by a number of investigators, including Rosse, Adams, Berndt, Minchin, and the Author.

Having once obtained our law of light-action, we can follow it through every possible combination of circumstances. And first we must ascertain its limits.

There are several conditions which must be fulfilled before the law can operate. There must be a considerable number of electrons ready to be liberated. If the light is concentrated on a small area, that number may soon be exhausted and the formation of new ions may be brought to a standstill. Many authors have found our law to fail for intense illuminations, and have therefore proposed the cube root instead of the square root as a guide for the resultant conductivity. But for still greater intensities we should again have to change the index, so that it is better just to make the proviso that the illumination must be moderate.

Is there a lower limit? In my own experiments I tried illuminations so faint as to be equivalent to starlight from a single star, and still found the law to hold good. But if the new "quantum theory"

is correct, no ionisation can take place below a certain amount of available energy. That amount of energy is excessively small,[1] but the eye is so sensitive that it can appreciate amounts of light down to the equivalent of some four hundred quanta falling upon the pupil per second, that being the amount of light received from the faintest stars.

On the whole, we may say that there is no inferior limit to the sensitiveness of selenium so long as there is plenty of time to observe the action. It is only when the time is short that a limit is set to what we may discover.

When the light is very feeble, the number of ions produced in a given time is very small, and the rate of recombination is very slow. For the feeblest illuminations it is, in fact, negligible, and ionisation proceeds steadily with practically no recombination. The number of free electrons mounts up at a uniform rate, and the pointer of our galvanometer will travel steadily across the scale.

But the rate of travel may be very slow, and disturbing causes may become so important in comparison that the experiment may be rendered useless. Selenium is very sensitive, for instance, to changes of temperature, and these may so distort the results that no conclusions can be derived from them. Such disturbances set a limit to the length of time for which we can afford to wait for a result.

We must next consider short intervals of time.

[1] Its amount is $5{\cdot}2 \times 10^{-11}$ erg.

If the light is very feeble, a short exposure to it is of no use, as the ionisation will not have time to become perceptible. But if there is plenty of light, even a short exposure may give a clear and useful result. For however short may be the exposure, the amount of ionisation will be proportional to the intensity of the light, since recombination will not have time to set in and affect the result. If the exposure occurs in short flashes, the variation of conductivity between the flashes will be *proportional to the intensity of illumination.* This is another simple law which is of value if we wish to compare various amounts of light.

It is obvious from the above considerations that a clear distinction must be drawn between the effect of instantaneous illumination and the effect of prolonged illumination. The discrepancies between the results of former observers are largely due to a lack of this distinction. We may put the difference as follows:

(1) The effect of prolonged illumination is proportional to its square root.

(2) The effect of short illumination is proportional to the intensity of illumination and to the time interval.

Now let us see how these rules affect the use of selenium for discovering and detecting light of various kinds.

Let us take a graphite selenium tablet which, with 20 volts, has a resistance in the dark of 20,000 ohms,

which falls to 10,000 ohms on illuminating it with a candle placed at a distance of one metre. That amount of illumination is known as one "metre-candle," or one "lux." The current in the dark will be one milliampère, and in the light its final value will be two milliampères. That final value will be attained in about five seconds.

In order to deal with smaller amounts of illumination, let us use the words "millilux" for one-thousandth of a lux, and "microlux" for one-millionth of a lux. The words milliampère and micro-ampère, similarly, are in general use for one-thousandth and one-millionth of an ampère respectively.

If we place the candle at a distance of a thousand metres on a dark night it will just be clearly visible. The illumination produced by it will then be one microlux, since it varies inversely as the square of the distance. The instantaneous effect of the reduced illumination will be one-millionth of the previous value, but the final effect will be one-thousandth, that figure being the square root of one-millionth. We shall therefore get a micro-ampère on our galvanometer instead of a milliampère. That is quite a large current compared with the smallest currents which we can now measure. It will, however, take over an hour before the full effect is obtained. That would be inconvenient, so it is better in actual practice to limit the exposure to a short time, say, one second, in each case. That exposure will, in cases of faint light, rank as an "instantaneous"

exposure. We shall then get the following currents with the candle at various distances :

1 metre	. . . .	$\frac{1}{2}$ milliampère
1,000 metres	. . . .	$\frac{1}{2}$ micro-ampère.
400,000 ,,	. . . .	$\frac{1}{800}$,,

Now this last distance is the distance between London and Edinburgh. The current obtained, though very small, is easily measurable with delicate instruments, so that we should discover the presence of a lighted candle at a distance far beyond the range of human vision. If we make the distance a thousand times greater yet we attain the distance of the Moon, and the current obtained from the candle at that distance sinks to a millionth of a micro-ampère. Even that minute current is by no means beyond our range, for currents of that amount have often been measured with an Einthoven String Galvanometer provided with a silvered quartz fibre. Indeed, there is a way of measuring currents ten or even a hundred times smaller yet, by means of a delicate electrometer. But let us rest content with our result, which means that if anyone were to strike a match on the Moon, we could discover the fact on earth by means of selenium, even without a telescope. And that feat could be accomplished in one second !

Matters are none the less remarkable if we do use a telescope. For the selenium cell, which considerably surpasses the unaided eye as a detector of light, would benefit by the telescope to the same extent as the

eye. The great telescopes of America will never be utilised to their fullest extent until they are used with selenium cells in their eye-pieces.

There is another direction in which selenium far surpasses the eye. It is a well-known fact in photometry that the eye cannot distinguish a difference of brightness much under 1 per cent. Suppose that two rooms are divided by a large door or partition of ground glass and that one of them is illuminated by a cluster of lamps, a hundred in number. There will be a uniform bright glow on the ground glass as seen from the other room. If now one of the hundred lamps is extinguished, the observer may, with close attention and a well-trained eye, just discover the fact of the 1 per cent. extinction. With selenium this extinction could be revealed by a considerable movement of the pointer of a galvanometer. The Author tested this by the following experiment. A ground glass 2×2 inches was illuminated from above. Below it was placed a selenium cell connected with a Broca galvanometer and a battery of 20 volts. A black thread was then stretched across the glass, in contact with the ground surface. It cut off 0·6 per cent. of the area of illuminated glass, no matter over what particular part of glass it was stretched. The thread produced a deflection of twenty divisions in the galvanometer. This showed that a thread twenty times finer could have been discovered, which would have been thirty-three times

less than any change of illumination discoverable by means of the eye, though aided by the best photometer ever constructed.

This fact opens up a new vista in human perception. It means that we can discover shades much more delicate than those seen by the eye. There may, for instance, be clouds in an apparently clear sky, clouds which the eye cannot see on account of its inability to distinguish very faint contrasts. Again, things become invisible by moonlight or starlight not because there is no light, but because our eye has, in the course of ages, been trained and evolved to see chiefly the contrasts presented to us by daylight. Owls, mice, and cats have not lost their power of seeing in the dark as we have. Their eyes remain sensitive to the delicate contrasts presented by a room lighted by only the diffused gloaming of the night, or by the faint glow of the cat's own retina. There is, however, no reason why we should not recover that power by means of selenium. No "nightglass" or other telescope will enable us to do so, for no optical instrument is capable of increasing the contrast of extended surfaces. It can grasp a greater amount of light from a distant point source and so render visible a star invisible to the naked eye. But it cannot help us to distinguish the windows of a building a mile away in starlight, nor to find an enemy crawling towards us in the dark. It is quite conceivable that an instrument may be devised on the basis of the properties of selenium,

which will, in effect, turn the night into day so far as visibility is concerned.

The scientific importance of an enhanced perception of contrast can hardly be exaggerated. There are many investigations of liquids and solutions where an accurate estimate of transparency is essential. The first trace of a certain coloration or turbidity may be most important, and the eye is sadly deficient in the perception of such faint changes of luminosity. Hitherto, the only practical way of increasing the contrast of extended surfaces has been by means of photography. A faint contrast can be exaggerated by suitable methods of development. This is often a fault in portraits or landscapes, which turn out "harder" than they should, owing to an exaggerated contrast appearing on development. Purely optical instruments, such as telescopes and microscopes, are quite unable to increase the contrast of surfaces. All they can do is to spread the image of an object over a larger portion of the retina and increase its general brightness. The use of selenium will mark a new departure in the range of optical instruments.

The actual mechanism of the ionising action of light is still somewhat obscure. But if some electrons are revolving in orbits round the atomic nucleus, under the influence of the attraction of its positive charge, any alteration of the electric field may convert that orbit from a circle or an ellipse into a parabola

or hyperbola, and so lead to the expulsion of the electron from the atom.

Such an expulsion of electrons actually takes place in the filaments of the thermionic valves used in wireless telegraphy. In this case the disturbance of the orbits is produced by the violent collisions between the atoms due to heat. Polished zinc will expel electrons under the action of ultra-violet light alone. Radioactive substances, such as radium and thorium, expel electrons spontaneously. X-rays are also effective in ionising selenium, but as they are much more penetrating than light-rays, a thicker layer can be used, and then the ionisation takes place through the whole substance. A thick plate of selenium can be used in order to determine a "dose" of X-rays, by observing the change of resistance in a slab of selenium.

When we study the influence of colour on the effect of light, we find that red is by far the most effective in lowering the resistance of selenium. This does not necessarily mean that selenium is more sensitive to red than to the other colours. For in nearly all spectra which we command, there is more energy in the red than in the other colours. The maximum of energy shifts from the red end of the spectrum towards the violet end as the source of light gets hotter. The maximum effect on selenium shifts in the same direction. If we cut off the infra-red radiations, we cut off 26 per cent. of

the effect, if we use a Nernst lamp as a source of radiation. If we cut off the ultra-violet rays as well, the effect is reduced another $1\frac{1}{2}$ per cent. In that case, the effective rays are mostly those of visible light. In sunlight the share of the visible rays is over 80 per cent. This is because the sun is hotter than any terrestrial source of light, and the maximum energy, instead of being in the infra-red, lies within the visible spectrum.

If selenium is sensitive to one colour rather than another it is particularly sensitive to blue light. Blue light is more effective in its action on selenium than red light possessing the same energy. But selenium is not markedly "selective." It is content to take its energy from the spectrum wherever it can find it in greatest abundance.

It is certain that the law of light-action is the same for any kind of light, though the amount of action differs from one colour to another. Selenium can therefore be used with light of any colour, though it is usually best to employ red light as being the most "energetic" in terrestrial sources of light. Selenium cells can be "tuned" to different colours by covering them with coloured glasses. We can thus construct an automatic colour analyser, the amount of such primary colour present being indicated by a separate galvanometer.

The equation to the recovery curve of selenium after illumination is

$$\frac{1}{N} - \frac{1}{N_1} = Bt$$

where N_1 is the number of electrons set free by the light and N is their number at a time t. B is a constant.

The equation to the curve showing the light action is

$$dN/dt = C - BN^2$$

where C is proportional to the intensity of the incident light. This is equivalent to the equation

$$N = \sqrt{(C/B)} \tan h \ (t \sqrt{C})$$

from which the light action of selenium in any given circumstances can be deduced.

CHAPTER IV

APPLICATIONS BASED UPON RELAYS

THE year 1880 was memorable in the history of selenium in several ways. It was the year of Graham Bell's Photophone, and it was also the year when Shelford Bidwell first made a beam of light ring a bell. These two events seemed to place selenium in the very front rank of scientific and practical interest, and few people would have thought that another thirty years would elapse before the next steps were taken. But that sort of thing often happens in scientific discoveries. Twenty years elapsed between the discovery of induced currents by Faraday and Henry and the first practical dynamo-electric machine.

Sometimes, indeed, a progressive step is taken in the dark, and is never found again. Every scientific investigator will have experienced this. It is a great mistake to assume that when a discovery is made it is a permanent acquisition of the human race. Many things may conspire to deprive us altogether of the use of the discovery. In the Middle Ages, when it was dangerous to be known to pursue natural knowledge and other " black arts," discoveries

were usually hidden away in cryptograms or died with their discoverers. We live in happier times now, but there are certain essential conditions which must be fulfilled before a discovery can see the light of day. In the first place, it must be capable of repetition. If Berzelius had found selenium in the residue of iron pyrites once, and had failed to find it again, his discovery would have been lost for a long time. Secondly, the discoverer must be convinced of the novelty of his discovery. If he thinks his observation has been anticipated by somebody else, he will not say much about it, nor take much interest in it himself. Thirdly, he must publish his discovery. This sounds easy, but often it is quite the most difficult part of it. He might write a letter to *The Times* or to *Nature*, but these journals would not publish his letter unless they knew the discoverer by reputation and were convinced of his judgment and trustworthiness. Failing them, he might present a report to a learned society. He can only do this through some member, and even then his paper will be referred to experts, who will be influenced by their personal or general knowledge of the writer. He might, of course, print a pamphlet independently and circulate it, but the scientific world would thereupon condemn him unread, arguing that if it were a true discovery, some scientific journal or society would have announced it.

Another element which often contributes to the neglect of discoveries is their possible commercial

value. An electrical engineer, seeing Mr. Bidwell ring a bell by means of a beam of light, might argue like this: "This discovery is either of commercial value, or it is not. If it is not, I take no interest in it. If it is, he has probably patented it, and I must give it a wide berth." So he waits until, fourteen years afterwards, the patent has expired. And as it is difficult to manufacture anything profitably in open competition, nothing more is heard of the invention.

It was Edison himself who used to say: "Marketing is 95 per cent. of an invention," meaning that for every day spent on the invention itself, nineteen days would have to be spent on the business of finding a market for it.

The world is only slowly waking up to the fact that discoverers and inventors are the most living part of the human social organism. They are the grey brain-matter, the cambium layer, the formative part of the whole. When life is not experimentation, it is routine, and of these two things, the former is surely the more alive. The organisation of research in the modern universities, the Nobel prizes awarded for great scientific discoveries, the medals and prizes given by learned societies, these are all encouragements to pure research which bear rich fruit. The prizes sometimes given by journals for some definite achievement, such as the *Daily Mail* prizes for feats of aviation, are also valuable incentives, and have the advantage of being independent of the granting of

patents and the subsequent troubles of marketing. This system might be extended, with great advantage to humanity.

Inventions involving selenium partake more of the nature of "cambium" than almost any others. For selenium is peculiarly human. It shows fatigue and after effects, just like the human eye. It can, like the latter, accommodate itself to darkness, and shows a diminished sensitiveness in a glaring light. It has also certain vagaries and uncertainties which recall the difficulties of depending upon the human factor in any enterprise. But all these qualities should help to strengthen the alliance between mankind and the Moon-element. The difficulties need only be carefully studied to be successfully overcome.

Shelford Bidwell's feat of 1880 remained for a long time a mere curiosity, and his apparatus was relegated to the category of "scientific toys." It was only in 1900 that Clausen and von Bronk produced a signalling apparatus which could be used to indicate the lighting-up or the extinction of a lamp by the ringing of a bell. The idea was to indicate the continued lighting of a signal light (lighthouse or railway signal) in some important position. It made it possible to keep an automatic watch on, say, a distant lighthouse, by focussing its light on the selenium cell.

As a current passing through a selenium cell is not capable of ringing an ordinary electric bell, it has to be sent through a relay which automatically switches on the bell current. This relay is best made

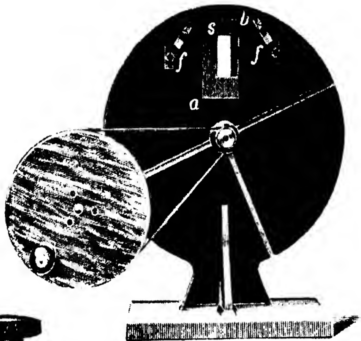

FIG. 8.
DISC FOR INTERMITTENT LIGHT.
(See p. 89.)

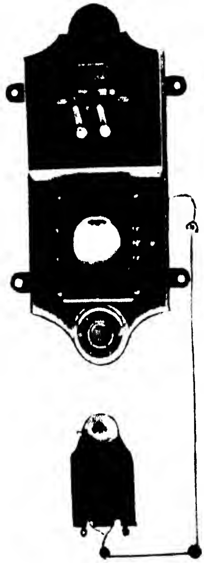

FIG. 5.
SELENIUM CONTROL.
(Pintsch.)

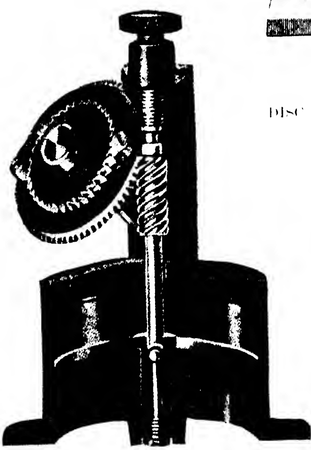

FIG. 19.
DR. BARR'S OPTOPHONE GOVERNOR.

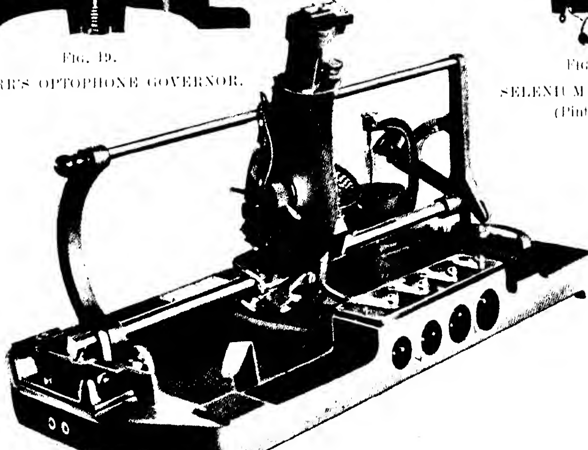

FIG. 18.
BLACK-SOUNDING OPTOPHONE.
(Barr & Stroud, Ltd.)

on the principle of the moving-coil galvanometer, first devised by d'Arsonval. A coil of wire, pivoted on the finest hardened pivots, moves in the magnetic field of a permanent magnet. The current from the selenium is sent through the coil, and as the resistance of the selenium is usually about 100,000 ohms, the coil may have a resistance of several thousand ohms without any disadvantage. Relays of this kind were made during the Great War by S. G. Brown, by Weston, by Sullivan and other makers and brought to a high degree of excellence.

An interesting apparatus for the automatic lighting of harbour buoys was invented and constructed by Julius Pintsch, Berlin, and tried in the mouth of the Elbe. The buoys were lighted by gas which was turned on automatically at nightfall and lighted by a small permanent flame. At dawn the relay worked the gas tap in the opposite direction and extinguished the buoy. (Fig. 5.)

An American project for the utilisation of selenium was a contrivance for sorting coloured objects, such as cigars or unroasted coffee beans automatically by their colour. The objects were allowed to slide one by one down an inclined groove. At a certain point they were exposed to a strong light. If they were of a light colour, they would reflect a good deal of the light, whereas if they were of a dark colour, they would not. The reflected light was received on a selenium cell, which actuated a relay if it received sufficient light from the object. The relay

moved a switch which directed the objects down a certain path, so that the lighter objects were all collected in a special compartment. By adjusting the relay to various shades the objects could be sorted and classified according to depth of colour.

The Great War of 1914–18 gave a great incentive to inventive activity among all the belligerents. In Britain, the use of selenium found a pioneer in Mr. H. Grindell Matthews, who had already distinguished himself by using wireless telephony to communicate with an airman in flight. He built a motor boat, which he called *Dawn*, and on this he installed a relay apparatus for controlling its movement by means of a searchlight. When the Zeppelin menace became formidable, he somewhat rashly offered to construct and control an aerial torpedo boat to be steered automatically from the ground and to attack the enemy in mid-air. His various attempts and achievements formed one of the romances of the war, and may well be set down here for the first time.

Finding some difficulty in the working of selenium cells, which he had to obtain from Holland by special messenger, he requested the Author to take charge of the design and working of the selenium apparatus. The *Dawn* was afloat on the Penn Pond, in Richmond Park! The searchlight used was of the torpedo-boat type, and had a 24-inch Parsons mirror. The arc light was supplied from a dynamo mounted on a traction engine. A large shed was erected near the pond to contain supplies and quarters for the night-

FIG. 29. MISS JAMESON AT LIVERPOOL (p. 145).
Dr. Barr on the right.

watchman, but the pond was not specially protected or railed off, so that any onlooker could have witnessed the experiments. But onlookers were very rare indeed, and as it was winter—the time referred to was November and December 1915—the Park was almost deserted.

The selenium cell which controlled the action of the boat—it was known as the Pilot—consisted of an octagonal cylinder composed of eight graphite-selenium tablets each measuring $3 \times \frac{1}{2}$ in., made by the Author. These eight tablets were carefully selected from a large number for their uniformity of quality. This was very important, as the boat would, of course, turn about a vertical axis passing through the axis of the cylinder, and the action had to be uniform all round. Any light-action on the selenium upset the balance of a "Wheatstone bridge" consisting of two "branches" of selenium (the "Pilot" being one of these) and two branches of graphite spread on "biscuit." This was done so that temperature changes should have no effect, as they would act equally on the illuminated and the unilluminated selenium. The requirements were that the boat should be able to (1) start; (2) stop; (3) turn to starboard; (4) turn to port; and (5) fire a gun, all these things being controlled by the searchlight. This was done by a sort of revolving commutator which put in the necessary switches in turn, the commutator being made to revolve by successive flashes of light acting on the selenium. It was

found quite feasible to pick out any one of the five actions by making the commutator run through its five variations and dwelling on the particular one wanted at the moment. In steering to port the *Dawn* lighted a red lamp, and in steering to starboard she lighted a green lamp.

While anxious days were being spent on trial trips, Mr. Matthews was undergoing a gruelling cross-examination at the Admiralty Board of Inventions and Research in Cockspur Street, then meeting under the Chairmanship of Lord Fisher. The greatest physicists of the country were assembled, and they turned the young engineer inside out, figuratively speaking, probing his knowledge of selenium and bringing forward all sorts of objections for him to answer. It was decided to subject the selenium tablets to a searching examination in one of the University Laboratories. This was done in the Author's presence. The tablets were exposed successively to extreme cold and to steam, to various vapours, to mechanical shock, and to prolonged and intense illumination. They "came up smiling" after every test, and their action remained faultless. No other selenium cells would have stood it.

Then a bargain was struck between Mr. Grindell Matthews and the Government. He was to have £250,000 if he could bring down a Zeppelin by means of an aerial destroyer worked by the new control. A deposit of £25,000 was to be made towards this sum as soon as satisfactory tests had been made with

the unmanned boat and some other applications of selenium.

For the day of the great test, the Author designed and constructed a selenium mine, consisting of a selenium relay with a telescopic lens 4 inches in diameter, directed towards the searchlight station half a mile away. On directing the searchlight upon the mine it was instantly fired by the action of the light on the selenium. As the image of the searchlight mirror was focussed upon a small diaphragm, the mine could not be exploded by any other searchlight, even if it stood close beside the first one.

The test was arranged for December 4, but the pond froze over that night, and it had to be postponed to the 7th.

When the great day arrived, there was a bright sun all day long, and we all felt very nervous, because the sun might affect the selenium and do its own steering, although the "Pilot" had been carefully shaded by means of circular discs of blackened brass spread over it horizontally.

But the experts did not arrive till four o'clock, by which time the sun had sunk low enough behind the trees to be well out of the way. We saw the cars coming over the distant ridges. The Author did the final tuning of the selenium cells and relays on the boat and then went to look after the mine, half a mile away from the pond.

The examining body arrived on the spot—a great array of talent led by Lord Fisher. The Chancellor

of the Exchequer and the First Lord of the Admiralty came, attended by a brilliant staff of the leaders of British naval and military opinion. Mr. Balfour stood by the searchlight, and commanded the evolutions to be performed by the *Dawn.* The little boat glided out from the small boatslip where she had been moored. She crossed the pond. A sweep of the searchlight, and she lighted her green lamp and turned to the left, performing a neat circle. Another touch of the luminous wand, and she made straight for the shore, but was stopped in time by a warning glance from the governing beam of light. She then started again and described figures of eight. For three-quarters of an hour the little boat careered twinkling about the pond, her red and green lights shining out alternately. It was the prettiest play of fairy lights ever seen. She finally fired her " gun " and returned to her moorings, with only her staunch selenium " Pilot " at the helm.

The Author had " set " the mine, ready for the other experiment. An eye-witness from the shore of the pond described the effect as follows : " We saw the beam of the searchlight swing round to where we were told the mine was placed. It touched the spot and instantly we saw the flash and the column of smoke. The report reached our ears two or three seconds afterwards. It was most impressive."

After the explosion, the Author was packing up the mine relay when he saw a messenger running towards him waving his arms. It was one of the

mechanics, with a message that the company assembled wished to see the experiment repeated. The Author thereupon connected up the relay to another detonator, focussed on the distant searchlight and withdrew to shelter. The beam came round again, and another explosion shook the air.

The test had been brilliantly successful, and the next day Mr. Grindell Matthews got his "deposit" of £25,000. He eventually worked the boat at sea at a distance of 3,000 yards in diffused daylight, and up to five miles at night.

But the rest of the money was never paid, for within a few months other means of fighting Zeppelins had been discovered, and were found sufficient to remove that menace from our shores.

Investigations concerning the possible use of selenium were continued for some time by the Admiralty, largely in a Selenium Laboratory placed under the Author's direction. One of the results of these investigations was Professor A. O. Rankine's grid photophone, of which we shall hear more anon. Another application was a method of dropping bombs from small unmanned balloons by means of a searchlight worked by either a friend or an enemy (preferably the latter). Some very successful tests of this method were made at the Roehampton Aerodrome.

Meanwhile, the enemy had not been idle. Recognising that the action of selenium is liable to numerous irregularities, Dr. Chr. Ries, a German authority on selenium, had constructed a differential selenium

relay, which only worked on exposing it to slowly intermittent light, and was then actuated by the *difference* of the conductivity in light and in the dark respectively—obviously a much more reliable action than any action depending upon the actual value of the conductivity.

But on the whole, there is no evidence that selenium was put to any actual military use during the war, not, at all events, with relays. The chief reason was that military men are shy of "delicate" mechanisms. A military adviser of the Munitions Inventions Department put the matter very tersely: "Micro-ampères," he said, "and military operations simply don't go together." Much can be said both for and against that dictum. After all, explosives are dangerous things to carry about, yet they are handled every day by soldiers with impunity, though a spark or a scratch might blow them sky-high. The safety lies in the adjustments and safeguards prescribed by the inherent dangers themselves. None of the mechanisms used in warfare are one-thousandth as complicated as the human mechanism itself, and yet the latter is what ultimately decides the fate of a battle and the history of a nation. It is often the most complex things which are also the safest.

CHAPTER V

PICTURE TRANSMISSION AND TELEVISION

EVER since the invention of the electric telegraph the transmission of pictures has been an inventors' dream. The dream has gradually—very gradually—come true. The slow progress made is largely due to a wrong conception of the difficulties of the problem. An artist will make a "lightning sketch" in a few minutes. A line here and there, a wash of colour in the right place, and the "picture" is complete. What inventors do not realise is that the smallest picture consists of several thousand dots. Even a "line" is really a row of dots, almost invisibly fine. The line *on the paper* may be continuous, but the image of the line *on the retina* is invariably discontinuous, and consists of a row of dots adjoining each other. A "wash" therefore means the creation of an immense array of dots—thousands of them—and before each dot can be put into its proper place, the telegraphic transmission becomes a very formidable matter indeed.

The first attempts were made to transmit handwriting and line drawings generally. A beginning was made in England by F. C. Bakewell in 1850.

He wrote with a gummy ink on a tinfoil-covered revolving cylinder. At the receiving end a similar cylinder was made to revolve at the same rate, and every time a gum line passed a certain contact a chemical action was produced on sensitive paper at the receiving end.

In 1856, Caselli, an Italian, exhibited in England an apparatus called a "pantelegraph," which had quite successfully transmitted from Paris to Marseilles not only writing, but plans, drawings, and pictures; but it was found that it suffered from the defects of Bakewell's apparatus, and was complicated and costly.

Twenty years after that the Post Office authorities in London conducted a series of experiments with D'Arlincourt's apparatus. The principles of this were similar to those employed by Bakewell, but a distinguishing feature was the introduction of an ingenious synchronous movement which rendered the revolving of the cylinders at the two stations absolutely uniform. With this instrument reproduction in blue, brown, red, and black, according to the nature of the chemical composition employed, was perfect; but it still had one drawback in common with its predecessors—that of slowness of operation. It was, however, used extensively by the French authorities for military purposes.

Shortly after this Cowper introduced his famous "writing telegraph." This introduced an entirely new principle—that of actuating a pen at the receiving station by merely writing with a pencil at the trans-

mitting end of the circuit. The system, however, necessitated the employment of two lines, through each of which passed currents smoothly increasing and decreasing in intensity. The pencil at the transmitting station was fixed to two arms, placed at right-angles. These arms directly actuated variable resistances, and thus varied the currents in the lines in accordance with the position of the pencil. Reception was by means of two needles magnetically pulling in opposition to light springs upon the recording pencil.

Although the "telewriter" has become a regular feature of certain classes of business, it must be admitted that any method depending upon the synchronic motion of two cylinders is bound to be complicated and costly.

Code Pictures

There is, however, nothing in the way of "coding" a picture, i.e. dividing it into a large number of dots and indicating the average shading of each dot or patch by a letter, which is telegraphed in the usual way. Such a transmission of a coded picture was made by the Author on May 24, 1923. It was, however, not transmitted by telegraph wire, but by wireless radiotelephony from the London Station of the British Broadcasting Co. It was the first attempt ever made to broadcast a picture, and as the time of transmission was limited to twenty minutes, the

result was necessarily crude. It being Empire Day, it was decided to "broadcast" a portrait of King George V.

The Author prepared the cipher message by coding a portrait of His Majesty. This was done by putting the original picture in an enlarging camera and projecting a magnified image upon a ground-glass screen marked out into 600 small squares, arranged in 30 lines of 20 squares. A code letter indicating the average brightness was then assigned to each square, and these code letters were then written out in 30 lines of 20 letters each.

The code letters and symbols were carefully chosen to facilitate telephonic transmission and subsequent reproduction. There were six of them, announced as follows: Stop, X, I, J, G, M. It was explained that "stop" was an ordinary full stop, or (if a typewriter was used) a hyphen. A blank space was indicated by the vowel O.

It will be noticed that these letters have very different vowel sounds, so that they can be distinguished even if the consonants are not clearly heard.

On Empire Day the code was explained and dictated by the Author. The dictation of the 600 letters took twenty minutes, although previous experiments had shown that an adult could easily take it down in eight minutes or less. Each line of 20 letters was divided into four groups of 5 letters each. This was to avoid confusion and facilitate

subsequent reproduction. The complete cipher message is given below:

1	. . . . .	. . . . g	j j j j j	g . . . .
2	. . . . .	. . g m g	j x g j j	g g . . .
3	. . . . .	. g m m i	. i g g g	j j g . .
4	. . . . .	. g . o o	o o o o o	. m m . .
5	. . . . .	g g . o o	o o o o o	o m j . .
6	. . . . .	m g o o o	o o o o o	. g j . .
7	. . . . .	m g . o o	o o . o o	i j j . .
8	. . . . .	g j i o .	x j g . o	i i j g .
9	. . . . .	m i j m .	g j x . .	i g j x .
10	. . . . .	m g . m .	g i x x .	j g i . .
11	. . . . .	g g g g .	o . . o .	j j g i .
12	. . . . .	j i g g .	o	i j j j .
13	. . . . .	g j m j i	x o . . x	g j o . .
14	. . . . .	g m m x m	m g i . .	j g . . .
15	. . . . .	j m g i g	m g g . i	i i g . .
16	. . . . .	j m g g g	m g m i .	x x o . .
17	. . . . .	j g m g j	g g m i i	x . . . .
18	. . . . .	. j j i g	x . . x x	x i j . .
19	. . . . .	. g j j j	x i i j j	i j g j .
20	. . . . .	. . g g j	i g m j i	j j i g j
21	. . . . .	. . m m x	m j i i i	j g m m m
22	. . . . .	. m m g .	m j . i j	g g g . x
23	. . . m m	m m m m .	m m m m m	m . . . .
24	. . g m m	m m m m .	g m m m j	x . . . .
25	g m m m m	m m m g j	m m g j i	. . . . .
26	g g i g m	m g g . x	i m j . g	g j i . j
27	m j i m m	m x x . g	m g g i g	g j i g j
28	g i g m m	m j j i g	g g g i g	j g j g g
29	j i g m m	m j j x i	g g j g j	g j g j g
30	i j m m m	m i i i	j g i i i	i g g g g

The picture was received and built up from the code on squared paper by some 250 "listeners" in various parts of England.

The limitation of a picture to 600 dots was, of course, a severe handicap. But no picture need have more than 10,000 dots, since the yellow spot of the retina—the portion of the eye which we all use for distinct vision—has only 10,000 separate nerve-

endings, and we could not "clearly" see more than that number of separate spots.

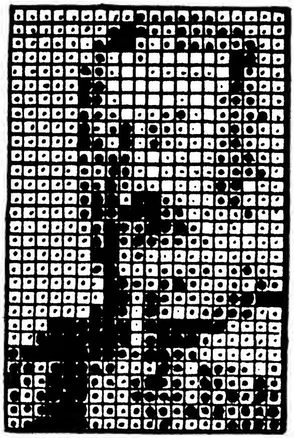

FIG. 7.—FIRST BROADCAST PICTURE.

Although this was the first attempt to broadcast a picture, the transmission of coded pictures by ordinary or wireless telegraphy had been carried out before. Mr. Sanger-Shepherd had transmitted coded pictures across the Atlantic, the code being automatically produced by a perforating machine worked by a selenium cell, the perforations in the same small area being from one to six in number, according to the brightness of the patch coded, and the perforations being optically recombined into a patch of the proper grade.

Synchronised Pictures

But the transmission of pictures by means of selenium was usually accomplished with the help of two synchronously revolving cylinders. This was done most successfully by Korn, who on November 8, 1907, transmitted a portrait of King Edward VII from Paris to London in twelve minutes.

The method was to draw the portrait in successive vertical lines, seventy-five to the inch. These lines

were graded by passing the original picture in front of a selenium cell which controlled a shutter apparatus at the receiving end, thus reproducing the portrait photographically.

Some such method was also used by Mr. Thorne Baker in England. More recently, selenium has been discarded in favour of bichromated gelatine, which gives an image in relief capable of actuating contacts on the revolving cylinder of the transmitting station.

Another contrivance which had been tried in this connection is the "photo-electric cell," a vacuum tube provided with two electrodes, one of which is a colloidal film of potassium or rubidium. When this film is charged negatively, it emits a stream of electrons under the influence of light, which instantly ceases on the restoration of darkness. This instantaneous action is a very valuable property, and would be still more valuable if the currents so obtained were not almost immeasurably small.

M. Belin, a French electrician, is said to have transmitted the shadow of a small square practically instantaneously by wireless telegraphy on the above principle, but it must not be forgotten that Ernst Ruhmer had attained a similar result by means of selenium before his death in 1913.

Such rapid transmission of pictures brings us within measurable distance of the solution of what is known as the problem of "television," or electric vision at a distance.

Television

Let us state the problem. A scene or object to be transmitted may be regarded as a changing picture. In order to reproduce it at the receiving end, the picture must be then presented as rapidly as a kinema picture, which changes some twenty times per second. If we can, therefore, transmit a picture in a twentieth of a second, we have solved the problem of " television."

We can at present transmit a picture in about five minutes. The present rate is, therefore, about six thousand times too slow. Can we accelerate it six thousand times ?

Let us put it in another way. A picture of, say, a human face cannot be divided up into less than some four hundred uniform patches without becoming difficult to recognise. We must therefore transmit four hundred signals twenty times per second, or eight thousand signals per second, and these signals must indicate the luminosity of each patch in at least six different grades. This, however, can be done by means of permutations of the Morse dot and dash, so that we have to transmit sixteen thousand signals per second. Can this be done ?

The answer is at present in the negative. There is no way of producing an action of light in a sixteen-thousandth of a second which could be effectively telegraphed, either by wire or by wireless.

Quite recently, however, the Author has found

that by using intermittent light of many different musical frequencies, each frequency corresponding to a separate portion of the original picture, it is possible to transmit these portions simultaneously by means of the same selenium cell. The musical frequencies are impressed upon the carrier wave of a wireless transmitter, and are reproduced in a loud-speaking telephone at the receiving station.

The picture is then " heard " as a medley of sounds, each sound representing a portion of the original picture or object to be transmitted.

The sounds are then analysed by a set of resonators, each of which picks out its own note and projects a luminous patch on a screen in its proper place. The original picture is thus reconstituted in a small fraction of a second.

As several hundred resonators can be employed, the problems of telephotography and television are thus brought nearer to their final solution to the same extent.

CHAPTER VI

OPTICAL INSTRUMENTS OF THE FUTURE

WHAT changes are likely to take place in our optical instruments within the next hundred years? The first telescope was made by Hans Lippershey in 1609. He was a Dutch watchmaker, who had a collection of all sorts of spectacle glasses. An apprentice of his happened to put two of them together in such a manner that they magnified a distant church tower. The master saw the possibilities of the situation and was quick to turn them to account.

Galileo heard of this and made up his own telescope in accordance with what meagre details he could obtain. The result was the Galilean telescope—the present-day opera glass—and the discovery of unimagined marvels in the sky.

The microscope had a steady evolution from the magnifying glass, already known to the Romans and the Chinese. It is now capable of magnifying some five thousand times, and a modification of it, called the ultra-microscope, is capable of showing the presence of much smaller objects by their diffraction images.

The functions of both instruments are very simple.

They serve the purpose of spreading the image over a larger portion of the retina and of increasing its general luminosity. They cannot increase the contrast of luminous surfaces, and this is a severe limitation of their utility. We have already referred to the possibility of selenium stepping in here to remove that limitation. Some years ago,[1] the Author put this possibility as follows:

"We must next consider the capacity of selenium for detecting small variations in brightness. This is a field hitherto entirely neglected, which yet opens up immense possibilities. We will assume, as before, that an illumination of 1,000 lux on a selenium surface of 100 cm. gives, with 10 volts, an extra current of 1 ampère. What is the smallest variation of illumination we can discover? The utmost limit of delicacy with which the eye can discover differences in luminous intensity, when armed with the best photometric means, is one half or one third per cent. This would vary the current by one quarter or one sixth per cent., or by, say, 2 milliampères. This is enormously in excess of the smallest current measurable. There is no reason, in fact, why variations as low as 1/100 or even 1/1,000 per cent. should not be discoverable with certainty. In experiments tried up to the present it was found comparatively easy to discover variations of 0·03 per cent.

"The importance of these facts in countless physical and chemical processes is obvious to any physicist or chemist. But let us carry the appeal before a more numerous class of readers by the following consideration. A landscape under moonlight or starlight is not as clearly defined to our eyes as a

[1] *Scientia*, September 1916.

landscape under daylight because we fail to perceive the contrasts. If there were any physical means of enhancing these contrasts the difference between a landscape by day and the same by night might be considerably reduced or even annulled. Now it is a well-known law of optics that no optical system or instrument can alter the intrinsic brightness of an extended surface, though it may make a point source appear more luminous. It is therefore impossible to obtain a telescope which will increase contrasts of contiguous surfaces. If, on the other hand, we could use selenium as an intermediate receiver, and retranslate its indications into light, we might make a nocturnal landscape appear as clear as day—an obvious advantage for military and other purposes."

Every user of a large telescope will have noticed that as the magnification of an object, such as the Moon, is increased, the contrasts become more and more vague, until the Moon's surface appears but a patchwork of cloudy blurs. That is because with every new magnification the gradient of contrast becomes less steep. If we could utilise the contrast-discovering powers of selenium we might, for instance, discover details on the floor of that mysterious large crater known as Plato which have hitherto defied detection.

But quite apart from this possibility, there is much reason to believe that our optical resources, which for centuries have developed along the same grooves, are capable of entirely new departures.

Take the case of the projector or searchlight. The principle of the searchlight is to place a small but

intensely luminous source at the focus of a parabolic mirror, so that a beam of parallel light may issue from the mirror. The diameter of this beam to begin with is the diameter of the mirror itself. It would remain of the same diameter if the source were a geometrical point. But no visible source of light is small enough to be considered as a geometrical point, and so the beams diverge. That divergence is not obvious. It is a curious circumstance that during the war many trained electricians and physicists were under the impression that the diameter of a searchlight beam is the same, say, at half a mile as it is where it issues from the searchlight mirror. It certainly *looks* as if it were quite parallel, as seen from the mirror. But if it were, it would appear to converge in the distance, like railway lines. The very fact that it appears not to converge should have shown them that in reality it diverged and spread.

Now consider the effect on a small object, say the dial of a clock a mile away. If we reduce the diameter of the mirror and reduce its focal length in the same proportion, we can also reduce the size of the luminous source. As a result, we shall have the same result on the distant clock face as before. And we shall have saved ourselves the trouble of constructing a large and expensive mirror. Not only that, but the source of light will be cheapened in proportion.

Now a hundred small mirrors or lenses are much cheaper than one mirror or lens of the same aggregate surface. We should, therefore, gain considerably by

using a large number of small optical systems instead of one large one.

That is what the insects do. Their composite eyes are one of Nature's experiments which has stood the test of time. We ought to construct receiving instruments on the same principle. It is true that we cannot directly apply such composite instruments to our eyes, but we can recompose a picture from the elements yielded by the several lenses and then contemplate it.

We can make our elementary searchlight beam as narrow as we choose by suitably increasing the focal length of the lens or mirror. We can do the same with a composite telescope, so that there is nothing to hinder us in making whatever fine-grained analysis we please of a distant object.

The impending solution of the problem of television will bring us face to face with these new aspects of optical data, and will open up enormous vistas of scientific and practical advancement.

CHAPTER VII

CONVERSION OF LIGHT INTO SOUND

We have already seen in Chapter III (p. 54) that the instantaneous effect of the impact of light on a selenium cell is what physicists call a "linear" one, meaning that it increases directly as the duration of the illumination. This relation enables us to calculate for any given intermittent illumination the amount by which the current in the selenium circuit will vary.

Let us take an example. A light of a hundred candle-power, shining upon a selenium cell placed at a distance of one metre, produces a current of one-tenth of a milliampère in one-tenth of a second. Then in one-hundredth of a second it will produce a current of one-hundredth of a milliampère, or ten "micro-ampères." Similarly, in a thousandth of a second it will produce a current of one micro-ampère. Now what happens if we throw such a beam upon a selenium cell every other thousandth of a second? Obviously, there will be five hundred flashes per second, each lasting for that short interval of time, and each of them will temporarily give rise to a current of a millionth of an ampère in the circuit.

Let us send that current through a sensitive telephone receiver. The telephone will instantly respond and will sound a note one octave above the middle C of the piano. We shall have "converted light into sound" through the medium of an electric current.

That this "conversion" is symbolical rather than actual is evident when we consider the enormous disproportion of sound-waves and light-waves. Sound-waves are measured in feet, and are represented by the lengths of organ pipes. Light-waves are from forty thousand to seventy thousand to the inch, according to their colour. In duration they are even farther apart. If we could slow down an average light-wave until it took one second to pass us, and could slow down an average sound-wave in the same ratio, it would take no less than two hundred million years to pass by!

In spite of this enormous disproportion, it is a remarkable fact, recently established by very painstaking researches, that the smallest amount of energy perceptible as sound by the ear is just about the same in amount as the smallest amount of energy perceptible by the eye as light. If the new "quantum theory" applies to both forms of energy, it means that both our senses have accommodated themselves to the minimum quantity of energy in existence provided it comes to us in a constant succession of pulses frequent enough to produce an impression of continuity.

An apparatus for " converting light into sound " is shown in the illustration (Fig. 8, p. 67).

The round case contains a glass plate on which sections of blank paper are mounted, leaving a series of radial slits. These pass the aperture *a* when the handle is turned and the adjustable slit *s* transmits light when each radial slit passes. The springs *ff* are intended to clamp a selenium cell in front of the slit *s*. If the cell is put in circuit with a battery and a telephone, a musical hum is heard which rises in pitch as the speed of rotation increases. It is best to place a bright lamp on the other side of the case. If an object is passed between the case and the lamp the sound ceases *instantly*. There is no lag or after-effect whatever.

Since the fluctuations of current are greatest at the lowest speeds, we might naturally expect the lowest notes to have the loudest sound. But that is not the case. The reason is that the human ear is not particularly sensitive to sounds of a low pitch. If they do sound as loud as higher notes, it is because their energy is much greater. A male voice expends much more power than a female voice if both speak equally loudly. A baby's voice, though it may sound very loud, consumes least energy of all. This means that nature has made our ears respond most readily to those cries which convey the greatest need of help. Would that such could be the general law !

We shall see in the next chapter how this " con-

version" of light into sound has been utilised to relieve the disabilities of the blind.

As the question of reversing the process and "converting sound into light" is likely to become a pressing one in the near future, we may here briefly consider one method of accomplishing this conversion.

It was recently worked out by the Author, and consists of receiving the sound in a tube having a vertical portion closed with a thin rubber sheet stretched horizontally.

Mercury is carefully poured on this sheet until it forms a drop about one-third of the diameter of the rubber sheet. The surface of the mercury is observed by daylight or artificial light. As the sound of the music or speech is received, the mercury is observed to "crimp" itself into an ever-changing variety of patterns. The remarkable thing about these patterns is that they are produced instantaneously, and remain unchanged so long as the sound remains unchanged. They are extraordinarily sensitive to variations of pitch, and therefore furnish a severe test for a singing voice.

A better view of the patterns may be obtained by throwing the beam of a torch lamp slantingly on to the mercury and receiving the reflected light on a screen of ground glass, taking care that no direct light falls on the latter. But the best way is shown in the diagram, Fig. 9. Light from an arc lantern or a gas-filled lamp is received by a lens so as to

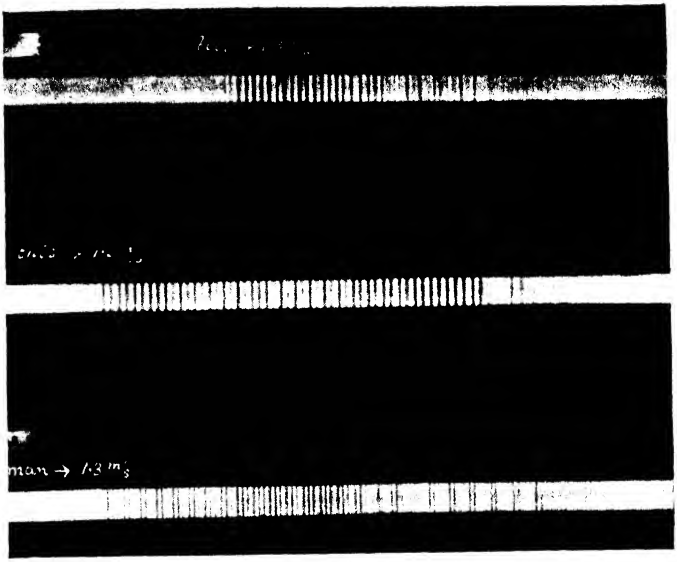

FIG. 31. DR. RANKINE'S RECORDS OF THE WORDS "BEET," "THIS," AND "MAN."
(See p. 158.)

FIG. 11.—TONOGRAM, NOTE B FLAT.

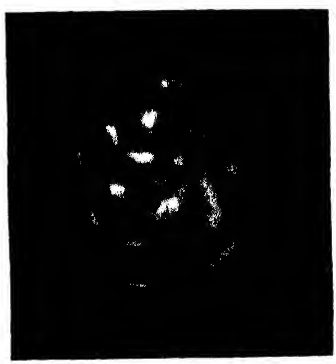

FIG. 10.—TONOGRAM, NOTE F.

produce parallel rays. The beam is reflected vertically downwards on to the mercury, which reflects it upwards into another prism. The latter, in turn, reflects it into the original direction until it falls on to a screen.

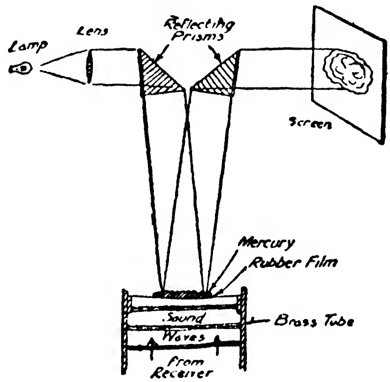

FIG. 9.—DIAGRAM OF TONOSCOPE.

The tube holding the mercury may be substituted for the visible horn of an old-fashioned gramophone, in which case the gramophone tune will be very graphically shown. Or the brass tube may be turned aside at the bottom in a horizontal direction and used for receiving the spoken voice. The photographs show some voice records produced in this way. It will be seen that the higher the pitch the smaller is the wave on the pattern. (See Figs. 10 and 11.)

The waves remain stationary so long as the note is kept at the same pitch. They are produced by the rubber communicating its vibrations to the edge of the mercury drop. The waves travel to the centre of the drop and then out again, the incoming and outgoing waves combining to form the stationary wave patterns, much as we can see them do at a vertical sea wall when the waves are coming straight towards it.

CHAPTER VIII

OPTOPHONE READING FOR THE BLIND

The present chapter will give an account of how the reading problem of the blind was completely solved by means of selenium so far as printed books and newspapers, as well as type-written documents, are concerned.

It will tell how the first attempts at a solution were made, what difficulties were encountered, and how the final solution of the problem was received by those entrusted with the welfare of the blind.

In the year 1910 the Author was appointed Assistant-Lecturer in Physics in the University of Birmingham. The salary attached to the appointment—£150 a year—was not exactly a tempting one, but the duties were light and the real attraction lay in the magnificent equipment of the Physics Department of the University, which had just opened new buildings at Bournbrook. Professor Poynting, who held the Chair of Physics, was a man of world-wide repute, and he had taken care that the new Physics Department should be the last word in facilities for research. Moreover, he administered a special fund amounting

to £150 a year to be spent on new apparatus, the gift of a well-wisher of the University.

With the active encouragement of the Professor, as well as of the Principal of the University (Sir Oliver Lodge), the Author started a research on the properties of selenium, feeling sure that that elusive element would amply repay a further prolonged study. He particularly investigated the manner in which selenium violates Ohm's law and the way in which the effect of light varies as the illumination is reduced to the lowest effective amounts. After reading papers embodying the results of this study before the Royal Society, he turned his attention to certain practical applications which had occurred to him. One of these was the utilisation of the action of light on selenium for the purpose of recording star transits. He succeeded in making Aldebaran, a first-magnitude star, ring a bell in its passage across the meridian, and also in making it work an electric chronograph. This was done by means of a 3-inch transit telescope (which had been used for timing the London coach in the days before railways were built) and a Kelvin mirror galvanometer.

Having obtained these considerable mechanical effects from very small amounts of light, the Author proceeded to study the question of making the wonderful properties of selenium available for relieving the disabilities of the blind.

The fact that light could be made to ring a bell showed conclusively that in one respect, at least,

the ear could be substituted for the eye. But that fact had been known for some twenty-five years, during which the resources of science had increased almost immeasurably. It only remained to harness them to the work.

The Bell telephone receiver, invented in 1876, is an instrument of almost unsurpassed power to detect minute currents of electricity. The only radical improvement achieved since Graham Bell's days was the invention of the reed telephone receiver by Sidney G. Brown in 1912. This improved receiver, which worked a conical diaphragm of the lightest aluminium sheet by means of a reed attracted by magnets, was found to be capable of detecting currents of less than a millionth of an ampère, provided they were regularly interrupted. The Author perceived the value of this new detector and proceeded to apply it to the detection of light falling upon selenium.

Since selenium conducts electricity to some extent even in the dark, it was necessary to compensate the "dark" current by some arrangement of the circuit, such as the system known as the "Wheatstone bridge," which consists of four conductors arranged in a square, two opposite corners of which are joined to the poles of a battery, while the remainder are joined to the galvanometer or other detector—in this case the telephone receiver. If now one of the four conductors is a selenium cell, while the others are resistances of the same value as the dark selenium, there will be no current through the detector while the selenium

remains dark. But when it is illuminated, the balance of resistances will be upset and a current will flow through the detector. Since, however, a steady or slowly varying current produces no sound in a telephone, it is necessary to interrupt it. This is done by clockwork—in practice a small clock in which the escapement is replaced by a vane in steady rotation while one of the cog wheels is used to make contact with a spring.

This was the construction of the first exploring

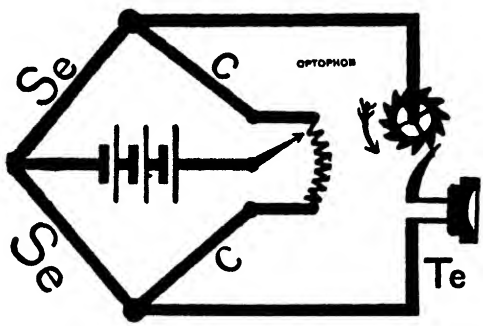

FIG. 12.—CONNECTIONS OF EXPLORING OPTOPHONE.

Optophone. It worked very satisfactorily, but the Author soon found that it was much more useful to discover contrasts of adjoining objects and surfaces rather than trying to gauge the brightness of surfaces as they came within range. He therefore adopted a Wheatstone bridge containing two adjoining selenium cells, both of which were exposed to the light object to be explored. In the annexed diagram, Se Se are the two selenium cells, and C and C are two graphite resistances of about 10,000 ohms

each, joined by a variable resistance of manganin wire.

The selenium tablets, resistances, battery and clockwork were built into a small case resembling a photographic camera, closed in front by an iris diaphragm. A telephone receiver was connected to the box by flexible wire. The whole apparatus was self-contained and quite portable. (See Fig. 13.)

The instrument was first shown in action at the Exhibition organised by the Optical Convention of the United Kingdom, held in the Science Museum at South Kensington.

The reception given to the exhibit by the Press was unexpectedly cordial. The invention seemed to fire the popular imagination, and if a gust of ephemeral fame had been the boon sought by the Author he had reason to be amply satisfied. As it was, the interest created by the invention strengthened his hands in facing the determined opposition called forth by later developments.

The *Pall Mall Gazette* of June 24, 1912, announced the first demonstration in the following whimsical paragraph :

" To-morrow the Optical Convention is to let loose a new invention on the world. An ingenious Birmingham scientist has turned the element of selenium to account by making light audible, and we are to be dazzled and deafened both at once. Sunlight makes a roaring sound, and lightning, presumably, anticipates its concomitant thunder. All we require now

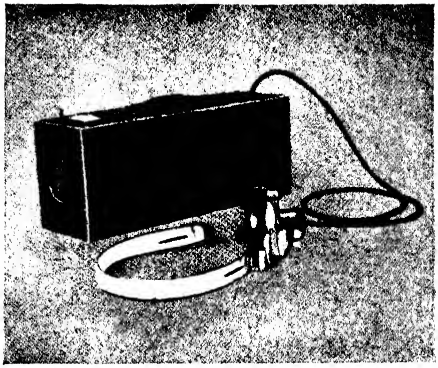

FIG. 13. THE EXPLORING OPTOPHONE, 1912.

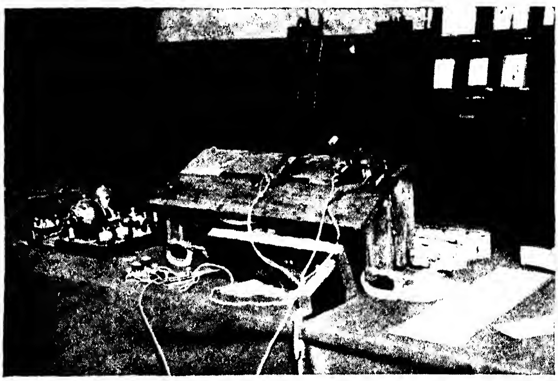

FIG. 15a.—FIRST READING OPTOPHONE, 1913.

is to increase the anticipative process, and then daylight will waken us every morning a couple of minutes before it arrives. What a point for the daylight-savers! Let us hope, however, that nobody will interfere to make darkness audible as well, for that would 'make night hideous' indeed."

A rather more sober announcement was made on the same day by the New York *Sun*:

Special Cable Despatch to the "Sun"

"LONDON, June 24.—Dr. Fournier d'Albe, a lecturer on physics at Birmingham University, will demonstrate to-morrow at the optical convention at South Kensington an instrument called the optophone, which is designed to enable those who are totally blind to locate and estimate light by means of the ear.

"The instrument is based on the property of selenium of changing its resistance when it is illuminated. This change is made to cause a current which, when interrupted by a special contrivance and transmitted through telephone receivers fitted to the head, gives an audible sound varying in loudness with the intensity of the light.

"The blind are enabled to locate lamps in windows and other high lights and to trace the outlines of large, well-defined objects. The instrument makes the moonlight distinctly audible and sunlight a roaring noise."

The *Daily News and Leader* of the same date published an interview with the inventor, which contains a forecast of the type-reading optophone:

" 'It is the first stage in making the eye dispensable,' said Mr. Fournier d'Albe. The initial difficulty of making the blind susceptible to light having been conquered, he is optimistic as to the results which further study and experiment may yield.

" 'The ultimate object, to provide a complete electrical substitute for the human eye, must be a matter of time,' he said, 'but by-and-by I hope to enable blind people to discover all sorts of objects in a room without exploring at all. To teach them to read print by sound may, of course, take years, but I am going to try.' "

The demonstration was given on June 25. Some blind persons had been attracted to it by the Press announcements, and one of them volunteered to test the apparatus. The account of what took place was given in the *Daily News* as follows :

" What happened yesterday was this : The blind man sat by a little table scattered with all manner of electrical contrivances, fixed the earpieces over his head, and took the black box in his hand.

" 'You are quite blind ?' asked Mr. Fournier d'Albe.

" 'Absolutely,' was the reply.

" 'Now, point the box in this direction, and tell me what you hear.'

" Mr. B—— obeyed. He pointed the box to the window. 'I hear a very rapid buzzing, like the whirring of a telegraph wire,' he said. 'Now the noise is growing louder and louder'—the box was pointing straight to the sun—'now it is very loud indeed——'

" Mr. d'Albe silently passed his hand over the aperture. 'And now ?' he queried.

" 'Complete silence!' was the reply.

"The light had been shut out, and there was no more whirring.

" 'Good!' remarked the inventor. 'I have tuned the machine to whirr when the box is pointed to the light, and to be silent when it is moved away from the light. Is that audible to you?'

" 'It is quite clear?' said the blind man. 'I can hear the light. . . .' There was a tragic little note of sadness in his voice."

The *Daily Chronicle* gave particulars of another kind of experiment:

"Another test applied to the same blind man was to equip him with the apparatus and start him to walk round the room with instructions to find a window. This he did several times without a single failure. The Optophone, as Mr. Fournier d'Albe explained, had been 'silenced for darkness,' and the moment the blind man approached a window the ticking or rasping sound became audible to his ears.

"He was listening to the light, as previously he had been listening to the shadows of the men who had passed in front of the Optophone."

Finally, an experiment was made at the suggestion of Mr. Arthur R. Burrows (now Director of Programmes of the British Broadcasting Co.). It was to see if the Optophone could be used to hear the light of a match. It so happens that selenium is particularly sensitive to low-temperature light like that of burning wood, so it is not surprising that the experi-

ment was completely successful (see illustration, Frontispiece).

Within a few weeks of the demonstration the news of the invention had travelled all over the world. A vast amount of correspondence reached the Author, some letters, written in the quaintest English, coming from Upper Egypt and India. They wanted to know more about "the machine that makes the blinds to see"—an exaggeration almost unavoidable when papers copy and translate from one another.

FIG. 14.—EXPLORING OPTOPHONE.

"You have had a magnificent Press," said a famous man of science to the Author. "Now if I had had a Press like that——" he smiled significantly.

But he was wrong. The people who mattered were the blind, and they can only be reached through the Institutions which care for their welfare. Sir Washington Ranger, the famous blind solicitor, wrote to the Author to say that he saw no utility in the instrument. "The blind problem is not to find lights or windows, but how to earn your living." The Author is ashamed to say that that point of view

had not occurred to him. He had imagined a blind person as surrounded by loving relatives, but chafing under the deprivation of the light of day. He had imagined himself being totally blind, and suddenly enabled to "watch" the day break and the sun rise by means of the new instrument. This reminder of the grim realities of the existence of the majority of the blind brought him back to earth. It also strengthened his determination to persevere in the development of the instrument until those responsible for the welfare of the blind should be compelled to acknowledge its usefulness.

After another twelve months of work he produced his first Reading Optophone, and showed it in action at the Birmingham meeting of the British Association on September 11, 1913. The following account appeared in the *Electrician*:

"Last year I described[1] and exhibited at the London Optical Convention an apparatus for converting light into sound by means of electrical effects, and proposed the name 'optophone' for such an instrument, as its primary object is not to transmit sound by means of light (photophone), but to 'see' by means of sound. In that original apparatus, two selenium 'cells' formed two arms of a Wheatstone bridge arrangement, and the equality of their resistances (and hence, of their illumination) was tested by means of a telephone in the 'galvanometer branch,' the current through this branch being periodically interrupted by clockwork. The apparatus enabled totally blind persons to discover the

[1] *Physikalische Zeitschrift*, 13, p, 942, October 1, 1912.

whereabouts of windows, lights and bright objects by the ear alone.

"The new 'reading optophone,' which was shown to the honorary graduates and other British Association visitors at Birmingham University on September 11, is a further development in the same direction. In this case, however, the light used is itself intermittent, and is indicated in the telephone by means of the current fluctuations due to the intermittent illumination of the selenium.

"It is well known that the conductivity of selenium is capable of following fluctuations of light with extreme rapidity, as shown by the successes already attained in the photophonic transmission of speech. The 'instantaneous' change of conductivity under the action of light is approximately linear,[1] so that the amplitude of oscillation, with a given intensity of light, is nearly inversely proportional to the frequency. This would mean that in converting light oscillations into telephone sounds the higher notes would be feebler than the lower ones. But this is largely counterbalanced by the resonance of the ear and of the telephone membrane, and it is found in practice that the maximum audibility occurs somewhere about the frequency of 1,000 waves per second.

"The reading optophone consists essentially of a selenium preparation illuminated by a line of light broken up into dots. The light of each dot is intermittent, and each dot has a different frequency. Thus, in one apparatus actually constructed, the frequencies of the eight dots composing a line 8 cm. long are in the ratio of the numbers of the diatonic scale, viz. 24, 27, 30, 32, 36, 40, 45, 48. Large type printed on gelatine or other transparent material, when interposed between the source of light and the selenium, breaks up the line into dots differing in

[1] Fournier d'Albe, *Roy. Soc. Proc.*, A 89, p. 79, 1913.

tone according to the shape of the letter, and with a little practice the letters of the alphabet are easily recognised and 'read' by the ear.

"The arrangement adopted is shown in the diagram. The line of light is furnished by an Osram 'striplite' of 100 c.p., which is concentrated by means of a cylindrical water lens upon a revolving perforated brass disc provided with eight circles with the numbers of holes specified above. The disc is

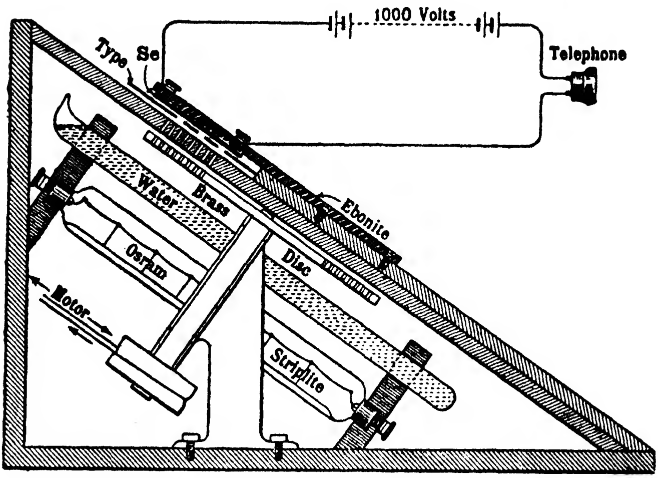

FIG. 15.—READING OPTOPHONE, 1913.

spun at about 20 or 30 revs. per second by means of an electric motor. The line of dots of eight different frequencies exists, therefore, just at the surface of the brass disc. As it is not feasible to bring the transparency to be 'read' into contact with the brass disc, the luminous dots are transferred to the upper side of a wooden partition by means of a set of glass rods with flat ends embedded in the wood opposite the luminous dots. The flat ends of the rods are flush with the surface of the board, and the

transparency can be safely and conveniently slid across them.

"The selenium bridge Se is mounted above the transparency with just sufficient clearance to allow for free displacement. The luminous dots transmitted by the type or other transparency impress their frequencies upon the selenium, and the latter gives a musical note corresponding to each dot, even when the beams of light overlap on to the same portion of the selenium. When that occurs with neighbouring notes, 'beats' are heard, just as they are when neighbouring notes on the piano are struck together.

"Since the only thing perceived is the alternation of the light and darkness, and since that takes place hundreds of times per second, the effect of light is instantaneous, and the 'lag' or inertia so unpleasantly associated with selenium is entirely absent.

"The smallest type successfully read so far is an inch high, photographed white as a transparency. But it is quite unmistakable. The two vertical strokes of H or M give a chaos of notes, the middle stroke of N gives a falling gamut, the three horizontal strokes of E give a chord, and the curved lines of O and S give characteristic flourishes of sound. The alphabet of capitals can be learnt in about an hour, and once the sounds are learnt, the process of reading may become as rapid as that of reading by sight.

"The selenium bridges used have a high resistance, amounting as a rule to several megohms. They require an E.M.F. of 1,000 volts for the best results. The telephones used were a pair of 4,000 ohms each.

"Since type of any size whatever can be put into the shape of a white-on-black transparency by means of photography, and simultaneously reduced to the proper size, the reading of type by the blind is now reduced to a matter of photography. This has over the Braille type the advantage of being generally

legible, though it is doubtful whether in the matter of cost the optophone can as yet compete with raised type.

"It is obviously desirable that ordinary black-on-white type, printed on paper, should be read optophonically. Some experiments I have made in this direction are very encouraging. A strip of slate long enough to cover the line of dots was cut out and perforated with holes so as to let the upper ends of the glass rods project just beyond its surface. The slate was covered with selenium and sensitised. A glass plate was laid over the wooden 'reading desk' and the glass rods, and a printed advertisement of large type was placed face downwards on the glass. The white paper produced a chaos of all the notes, which broke up into more or less well-defined notes as the black letters were passed over the rods. But the loudness and distinctness so obtainable were greatly inferior to what they are by transmitted light. Still, the solution is there in principle, and it is only a matter of making the type smaller and the effects louder and more distinct. The blind will then be able to read everything as well as the sighted.

"Needless to say, any succession or combination of musical notes can be picked out by properly arranged transparencies, and I have succeeded in transcribing a number of musical compositions in this manner, which are, of course, only audible in the telephone. These notes, in the absence of all other sounding mechanism, are particularly pure and free from overtones. Indeed, a 'musical optophone,' worked by this intermittent light, has been arranged by means of a simple keyboard, and some very pleasing effects may thus be obtained, more especially as the loudness and duration of the different notes are under very complete and separate control. As this, however, was not the immediate object aimed at in

devising the optophone it need not be further enlarged upon here."

It is interesting to note that the letters first read were made to give the full sound of all the notes on their vertical lines, just as they do in the latest type-reading optophone of the present day. But in 1913 this result was accomplished by making "transparencies" of the letters. The Author remembers making transparencies of the initials of the President of the British Association (Sir Oliver J. Lodge) and three of its honoured guests (Madame Curie, Professor Lorentz, and Professor Arrhenius) and teaching them to read them with the optophone (Fig. 15a, p. 98).

Immediately after the B.A. meeting the Author set to work on the final stage of the problem—that of bringing ordinary printed matter—which the blind call "ink-print" to distinguish it from "raised type"—within the range of the optophone. It proved a very formidable task indeed, as the amount of light to be "made audible" was two or three hundred times less than the amount actuating the first reading optophone. For not only was the type much smaller, and its area about a hundred times less, but it had to be worked with light *reflected* from paper, and diffused as well.

The Author recognised that the only chance of catching sufficient of the diffusely reflected light to produce a useful audible sound was to bring the selenium detector close up to the type. This could

not be done without intercepting the beam of light, unless the selenium detector was perforated, and then the amount of light caught on the selenium would only consist of the rays reflected sideways. But having obtained an audible sound by means of a sensitive S. G. Brown telephone, he constructed a selenium tablet on slate with a hole in it just sufficient to receive a beam of a width corresponding to the length of a letter of ordinary type. Thus he obtained the first "type-reading optophone," which he exhibited before the Royal Society in May and June 1914. The following is a report taken from the *English Mechanic*:

"At the meeting of the Royal Society on May 28, Dr. E. E. Fournier d'Albe, in a communication entitled 'A Type-reading Optophone,' described the latest development of his instrument known as the optophone, by which it is claimed that it is possible to enable the blind to read ordinary newspaper type, it being necessary for them to learn a sound alphabet that is about as difficult to master as the Morse code. Dr. Fournier d'Albe reminded the Fellows that two years before he had shown how it was possible, by taking advantage of the variations produced in the electrical properties of selenium under the influence of light, to enable a totally blind person to appreciate differences in illumination: differences of light become sensible as differences of sound heard in a telephone. The new form of the apparatus consisted essentially of a rapidly-rotating disc, perforated like a siren-disc, with several concentric circles of holes. A Nernst lamp was placed behind the disc, with its filament stretched radially across the circles. The

light, shining through the holes, gave regularly recurring flashes, which, when of suitable frequency, could be detected by means of selenium and a telephone. An image of this line of intermittently luminous dots was thrown upon the type to be read, and the light, diffusely reflected from the type, was received on a selenium bridge. As each dot had a characteristic note, the sound heard in the telephone varied with each variation in the reflecting power of the surface under examination. As the letterpress was moved on in the direction of the line of type, the sound changed rapidly with every change in the shape of the letters, and with some practice the type could be 'read' by ear. By means of an ordinary high-resistance telephone receiver, type a fifth of an inch high could be read. The effect became rapidly fainter as the type diminished in size; but ordinary newspaper type was readable with the help of a highly-sensitive Brown telephone relay.

"Dr. Fournier d'Albe's new form of instrument constitutes a very considerable advance on that which he showed last year in Birmingham at the British Association. It was then necessary for the type to be about 2 in. high, and to be printed in a transparent medium on a dark ground. In further explanation of the method, it may be stated that it is possible for musical notes to be produced in the telephone by variations in the electrical current passed through the instrument, the varying resistances of the selenium giving rise to variations in the electric currents produced. Roughly, Dr. Fournier d'Albe said, the sounds heard in the telephone embraced an octave, and the recognition of them depended on the ability of the user of the instrument to recognise which of the notes which might be heard was omitted, the difficulty of learning the alphabet

being comparable with the difficulty of learning the Morse code."

Such was the stage at which the optophone had arrived when the war broke out, and for some years the energies of "civilised" humanity were concentrated on mutual destruction. But the problem was completely solved in principle, and the Author could

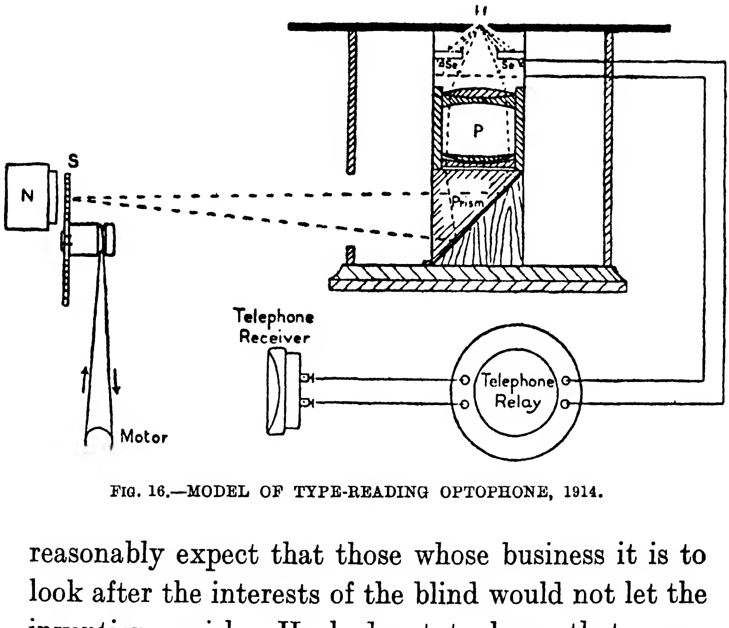

FIG. 16.—MODEL OF TYPE-READING OPTOPHONE, 1914.

reasonably expect that those whose business it is to look after the interests of the blind would not let the invention perish. He had yet to learn that every human institution is by nature conservative and shy of innovations.

One of the most effective ways of blocking the adoption of a new invention is to spread a report that a much better invention is shortly about to

appear. Those who, like the late Sir Arthur Pearson, had spent their energies lavishly in collecting funds for books in raised type printed on the Braille system, were anxious lest the fame of the new instrument should make Braille appear obsolete and thus dry up the constant supply of funds necessary for the upkeep of Braille literature. The following note, which appeared in the *Braille Review* for April 1915, either deliberately or unconsciously turns the tables by bringing forward a super-invention unsupported by any evidence except a letter from an anonymous American inventor, who obviously never tried the experiment he describes :

"An Instrument for Reading Ink-print

"Attempts have been made from time to time to utilise the peculiar electrical properties of the element selenium for the purpose of enabling the blind to read ordinary letter-press. It will be remembered that at the Conference last year, Dr. Fournier d'Albe of the Birmingham University gave demonstrations of his apparatus, the Optophone, which aroused much interest. By means of a powerful electric light the shadow of the ink-print letter is cast upon the plate of selenium which then emits varying sounds for the different letters. A specimen of this apparatus has since been acquired by The National Institute. We have now received particulars from America of a new instrument which, instead of converting the letters into sound, reproduces a much-magnified image of the letter in relief, which can then be recognised by touch. The following descriptive extract from the inventor's letter may prove interesting to our

readers: 'The device consists of an instrument which, being passed over the type, reflects a magnified shadow of the type through a dark tube, by means of a lens, on to a plate of selenium through which a current of electricity is passing. Selenium varies its electrical resistance in different lights. Above, and fused to the selenium plate are numerous wires connected in the circuit with small electro-magnets. Where the shadow or image of the type falls on the selenium the electrical resistance is greater, so that the magnets connected to the shaded parts of the selenium plate are supplied with less current, making them weaker than those magnets connected to the more illuminated parts of the plate. The duty of the electro-magnet group is to attract small iron pins. These pins are arranged by spiral springs to fly down only to those of the magnets whose attracting force is sufficient to contract the spring, i.e. the magnets receiving the strongest current, which are those connected with the selenium where most light is thrown. The pins over the magnets in the shadows stand out in relief, so that whatever shadow is thrown on the selenium plate is reproduced by the pin heads over the magnet group, and may be traced with the finger tip.' "

The absurdity of making an electromagnet actuated by a current through selenium strong enough to counteract "spiral springs" is obvious to anyone familiar with the properties of selenium, and the result would, even if successful, only substitute the finger for the infinitely more sensitive ear. Besides, it is well known that ordinary letters in relief are very difficult to read. Hence the superiority of the Braille dot system.

But a more serious rival arose shortly afterwards

in the person of Professor F. C. Browne, of Illinois, who had spent many years in research on selenium and had, in fact, founded a "school" of talented research students. He had found a way of producing large selenium crystals which were supposed to be particularly efficient in producing current on illumination. Three of these crystals he mounted in a box with a slit at the bottom, which was passed over large letters of ordinary type illuminated from above. Each of the crystals was separately connected with a battery and electric interrupter, but the three interrupters had different musical frequencies. It was, in fact, a combination of three "exploring optophones." This combination Professor Browne called a "Phonoptikon." On a description appearing in the *Scientific American* of August 14, 1915, the Author made the following comments (November 27, 1915):

"THE PHONOPTIKON AND THE OPTOPHONE

"*To the Editor of the 'Scientific American'*

"I find in your issue of August 14 an account of F. C. Browne's 'Phonoptikon,' which is claimed to be an improvement on my 'type-reading Optophone.' As both instruments are described as enabling totally blind persons to read ordinary type by ear, some remarks on the respective merits of the two instruments may not be out of place.

"The phonoptikon uses the net extra current obtained from a selenium cell mounted in a Wheatstone bridge when the cell is illuminated. This principle I adopted in my first exploring optophone

(1912), but I discarded it on account of the slowness with which selenium recovers from illumination. In the Reading Optophone I use the fluctuations of current produced by intermittent illumination, and thus I reduce the effect of lag to about 1-1,000 of a second. In fact, the response to light and to darkness is instantaneous. The available current is, of course, reduced in about the same proportion, so that sensitive telephone receivers of high resistance (8,000 ohms) have to be used. The telephone relay figured in my Royal Society paper I have also discarded, as it did not respond equally to different notes.

"The claim to distinguish all the ordinary letters by means of only three components arranged vertically I can hardly regard as serious. In any case, I found six the minimum number, and with these all letters could be distinguished. The greatest difficulty encountered is to distinguish between 'u' and 'n,' and even this was done without fail by Prof. Muirhead, of Birmingham, after ten minutes' practice. I see no advantage in moving the receiver over the printed page instead of vice versa. The great practical difficulty is to maintain a good alinement, and in the phonoptikon as illustrated I see no contrivance for doing so. In the optophone this is done on the typewriter principle.

"The two advantages which I do recognise in the phonoptikon are the absence of clockwork for producing intermittent light, and the fact that blank white paper gives no sound. On the other hand, there is a complex mechanism for current interruption; and the 'black' response, while making learning much easier, will not, in my opinion, sensibly affect expert readers. The difference is similar to that between various systems of shorthand, where ease of acquisition only tells in the first stages. Besides,

it is in general more appropriate that white should give a sound, and not black.

"Now that the problem of ordinary reading for the blind has been seriously attacked along two different lines (and with complete success along at least one of them), we may hope that the instruments may soon become generally available. Here in England the scarcity of Nernst lamps and high-resistance telephones, due to the war, has practically stopped the manufacture of the optophone for the present. But American inventors and manufacturers are entirely free to use its principle in any way they choose. The main point is that those dwelling in darkness should perceive the light.

"I am greatly interested in F. C. Browne's researches on selenium crystals, which clear up some hitherto obscure questions of theory. If these crystals are much more effective as receivers than ordinary 'cells,' it will be valuable, but I find it quite possible to obtain 'normal galvanometric efficiencies' of 100,000 microhms per lumen under standard conditions (1 volt, 1 lux, and ½ minute alternating exposure to light and dark) with cells provided with carbon electrodes. This is much in excess of the older results, and I should be glad to know whether the new crystals can surpass it.

"Yours truly,

"E. E. Fournier d'Albe."

When, some years afterwards, the Author met Prof. Browne at the Royal Society, the latter very freely and handsomely acknowledged the superiority of the optophone as a solution of the reading problem.

But the real clash was to come. In February 1917, the Author constructed an optophone embodying further improvements, and demonstrated it before

the Roentgen Society. He arranged various letters on cards, and showed that the cards could be shuffled and then read correctly by means of the optophone. He also invited the National Institute for the Blind to send some representatives to hear him read a newspaper on the optophone, only stipulating that if he did it successfully, they should testify to the fact of his having done so. After some delays, the test took place on March 28, 1917. It was reported in *The Times* as follows :

"READING BY EAR

"THE OPTOPHONE IN OPERATION

"At the Selenium Laboratory, 27, Maddox Street, W., yesterday, Dr. Fournier d'Albe gave a demonstration of optophone reading before a small company which included (here follow names of examiners and others).

"Experiments with the optophone have previously been described, but the demonstration yesterday was interesting as being the first which has shown the reading of small type by ear. Mr. Stainsby chose as a test passage the second leading article from *The Times* of March 27. The inventor was blindfolded, given the article, which he inserted in the optophone, and he then slowly but accurately began to spell out the sentences. The reading was achieved without an error.

"The speed attained was not more than three words a minute, but Dr. Fournier d'Albe believes that by practice a considerably higher speed can be attained. The line-changing mechanism places an outside limit of twenty-five words on the reader's progress. To use the optophone students have to

learn its alphabet, which is a kind of musical adaptation of the Morse alphabet. There are sound dots and dashes, but these are combined with a range of musical notes falling within the compass of an octave. The sounds are conveyed to the ear by a receiver."

The actual passage—the first piece of "ink-print" ever read by ear since the world began—was the following:

"An Agricultural Policy

"The Report of the 'Agricultural Policy Sub-Committee,' of which we published a brief summary yesterday, deals with one of the most important problems raised by the war, but relating to the future. The public and the"

Having accomplished this unprecedented feat, the Author naturally expected congratulations and acknowledgments from his examiners. He was informed, however, that they would draw up a report in due course.

The blow fell on April 14, when a letter purporting to emanate from Sir Arthur Pearson appeared in *The Times* and most other papers, to say that the test had been a complete failure as far as any utility was concerned. *The Times* letter ran as follows:

"Reading by Ear

"*To the Editor of 'The Times'*

"Sir,

"On March 29 you reported a trial of the optophone by Dr. d'Albe, who endeavoured to

demonstrate its practical value for the blind. I have it from Dr. d'Albe that he had practised 130 hours on the optophone used. How far short he fell of his expectations the following extract from a report submitted to me by the four experts of the National Institute for the Blind, who attended the demonstration, and two of whom were blind men, will show:

"'The speed which the inventor was able to attain—one word in one minute and a quarter—would be utterly useless. Dr. d'Albe's contention that increased speed was purely a question of practice is not convincing, for our knowledge of the optophone leads us to believe that the speed must always be so slow, and the use of the instrument so nerve-racking, as to make the optophone of little or no value to blind people, whatever may be its use in other directions. But even assuming that a satisfactory speed could be obtained, the expensive character of the instrument would put it out of the reach of the average blind person.'

"It is to be most sincerely hoped that Dr. d'Albe will in the course of time succeed in producing results from his ingenious invention which will render it worthy of serious consideration by those who have the interests of the blind at heart.

"Yours faithfully,

"ARTHUR PEARSON,

"*President, National Institute for the Blind.*"

224-6-8, Great Portland Street, W.

The letter to the *Lancet* was even more sharply worded. It contained the passage:

"I hope that Dr. Fournier d'Albe will now cease to issue misleading statements with regard to the practical value of the optophone as a means of

enabling blind people to read. It can at present be only described as an interesting scientific toy."

Truth made the cutting comment: "It is a pity that newspapers should give currency to fantastic stories of this sort, which awaken hopes only to blast them."

Had the most shameless charlatan and impostor made false and "fantastic" claims, which were blasted at the first test, he could not have received a more merciless punishment. It should, however, be stated in justice to the late Sir Arthur Pearson—a noble benefactor of the blind—that it was not he who wrote that letter, but a gentleman to whom he had delegated the use of his name for Press purposes.

In any case, the opposition had unmasked its guns. After that smashing bombardment it might very well have happened that the delicate structure had been levelled with the ground, and the optophone lost and forgotten for perhaps many generations.

In defence of his brain-child, the Author wrote in *The Times* (April 16):

"READING BY EAR

"*To the Editor of 'The Times'*

"SIR,

"In reply to Sir Arthur Pearson's letter in *The Times* of to-day, kindly allow me to state that I never considered it part of my business to acquire or demonstrate the maximum speed attainable in reading a newspaper by ear. That the optophone will enable a totally blind person to do this after, say, six

weeks' practice is now definitely established, and, as I am the only person who can speak from experience of the difficulties encountered, I may assure Sir Arthur Pearson that practising or reading with the optophone is no more 'nerve-racking' than reading wireless messages, and is, indeed, a very similar process. Sir Arthur Pearson's 'experts' do not state that I also offered to read type-written letters and even carefully-written manuscript by ear, but that they took that possibility for granted. I should be interested to know what further 'results' I am expected to accumulate single-handed before 'those who have the interests of the blind at heart' will deign to consider them 'worthy of serious consideration.'

"Yours faithfully,

"E. E. FOURNIER D'ALBE."

27, Maddox Street, W.,
April 14.

And in the *Westminster Gazette* (April 18):

"READING FOR THE BLIND

"SIR,

"I notice in your issue of the 14th inst. a letter from Sir Arthur Pearson regarding the speed with which a newspaper can be read by ear with the help of my 'optophone.' Before the last test was made, I expressly disclaimed having myself attained a speed of twenty-five words a minute, though such a speed should be only a matter of practice. The supremely important thing, now established beyond cavil, is that any ordinary book or newspaper can now be read by totally blind people. In January of this year not a single line of newspaper had ever been read by ear, neither by me nor anybody else. I read an unknown passage from a newspaper article

blindfold in presence of Sir Arthur Pearson's experts on March 28. I leave the friends of the blind to judge the true import of that achievement.

"Yours faithfully,

"E. E. Fournier d'Albe."

Selenium Laboratory,
27, Maddox Street, London, W.1,
***April* 17.**

But to most people the word of "Sir Arthur Pearson" was final concerning anything connected with the blind, and as the full weight of his name was flung at the unfortunate invention, its doom appeared to be sealed.

But it was but the darkness which precedes the dawn. Although the Author's resources were exhausted, and himself thoroughly discouraged, help was on its way. It came in the shape of an offer by a distinguished mining engineer, Mr. W. Forster Brown, to provide funds for the training of some blind pupils in optophone reading and for the construction of a certain number of type-reading optophones. This generous and public-spirited offer, prompted, no doubt, by the typical Englishman's sense of fair-play, proved the turning-point in the life of the optophone. It disappeared from the public view for over a year, and its opponents probably congratulated themselves on the success of their policy, but the final triumph was being quietly and steadily prepared.

In June 1917, the Author met the Misses Jameson (Mary and Margaret), daughters of Mr. Thomas

Jameson, of South Norwood, who were both blind from earliest infancy, but had received a liberal education and were expert Braille readers. He arranged to give them a series of lessons in optophone reading, which began on July 4, 1917. They were so successful that after twenty lessons of an hour each they were able to read their first complete page of ordinary print.

The optophone on which they read was provided with a gas-filled lamp of sixty candle-power, the filament being placed edge-wise to make it into a line of light. The instrument was not a portable one, so the lessons had to be given at 27, Maddox Street. When winter came, it was thought necessary to enable the pupils to continue practice in their own house, and several new types of a portable optophone were worked out. A very small motor was constructed, which drove the light siren disc by means of a thread. The motor had to be carefully insulated so as not to interfere with clear hearing in the telephone.

The instrument finally evolved by the Author, and provisionally placed on the market by the Medical Supply Association at the price of £35, is shown in the accompanying illustration (Fig. 17).

It was described as follows :

"A small disc, D, is made to rotate rapidly by means of a minute electric motor, turned on by the switch M. The disc is provided with five concentric circles of holes, the numbers in successive circles

being 24, 27, 32, 36, and 45 respectively (these correspond to the notes C, D, F, G, and B). The disc is illuminated from below by a small electric lamp and condenser turned on by means of the switch A. A slit found above the disc cuts out a radial portion, so that a line of five luminous dots is seen from above. A small image of this line is thrown upon the upper surface of the glass plate G, and is thus focussed upon any point laid flat upon the glass. The lamp, disc, and lenses are mounted on a carriage which can be moved from right to left by means of the handle H. The top of this carriage bears a selenium tablet, which is placed in circuit with a battery and telephone. The glass plate with its stand forms a book-rest, which will take any ordinary size of book or newspaper. This book-rest is moved to and fro at right angles to the printed line by means of the line-changing head L. This head moves with audible clicks, and by counting these clicks, the operator can make sure of getting the next line correctly into position.

"The telephone receiver is worn on the head, as is done without discomfort by all telephonists and wireless operators.

"Experience has shown that with good hearing (not necessarily a 'musical ear'), the alphabet can be learnt in about eight hours, and easy words and sentences in clear type can be read after from ten to twenty lessons. The acquisition of speed is entirely a matter of practice. The English alphabet holds good for reading French, Italian, Spanish, Portuguese and a number of other languages. Other forms of type have, naturally, their own characteristic sounds, and must be learnt separately.

"It is also possible by means of the optophone to read type-script, and as blind people can now use type-writers, it is possible for a business man to type

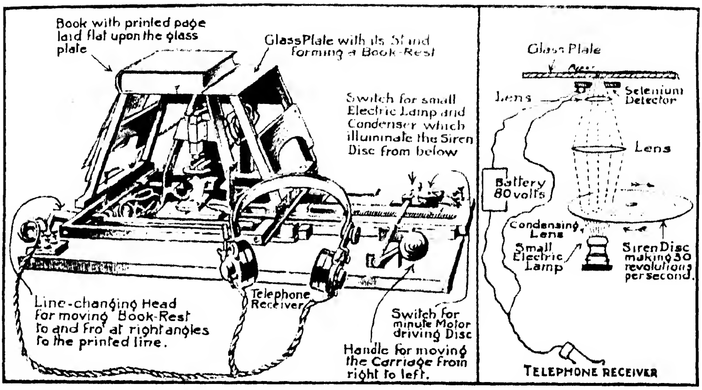

FIG. 17. THE ORIGINAL TYPE READING OPTOPHONE.

(From the *Illustrated London News.*)

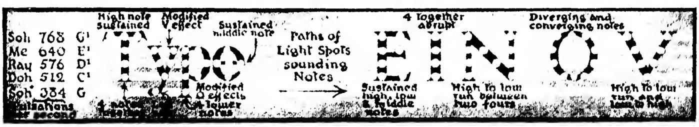

FIG. 28. BLACK-SOUNDING METHOD.

(From the *Graphic.*)

a letter, read it over, and read a type-written reply.

"Ordinary handwriting cannot be read by ear, unless it is written in careful imitation of type.

"Incidental uses of the optophone consist in the examination of pictures, photographs, maps, and dress materials."

This was the optophone—risen like a phœnix from its ashes—which came out into the world once more on August 27, 1918, at the British Scientific Products Exhibition held at King's College, London. The Author gave a lecture at which Sir Richard Gregory, F.R.A.S., Editor of *Nature,* presided. At the conclusion of the lecture Miss Jameson gave a test reading from Dante's *Inferno.* A page was chosen by the audience. Miss Jameson put the book on the book-rest of the optophone and began to read. The words she read were: "in the light." "Is that all?" said the Chairman. "Yes," said the blind reader. "There are only three words in this line, with a full stop after them." It turned out to be quite correct, and the words read seemed to many of those present to be very appropriate to the occasion.

That test, followed by other public tests, was too powerful to be extinguished even by the magic of Sir Arthur Pearson's name. There was another eruption of Press notices, and another avalanche of inquiries descending on the various Blind Institutions. The *Illustrated London News* gave a page of cleverly drawn diagrams, two of which are shown above (p. 124).

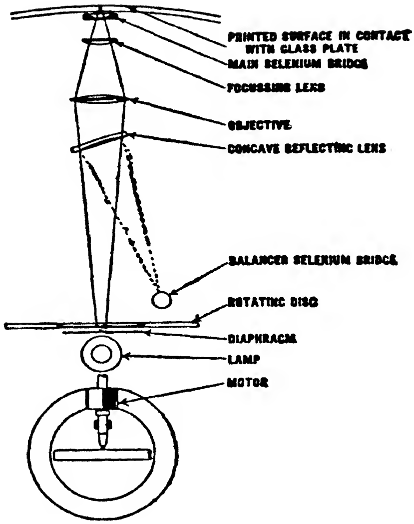

FIG. 17A.—OPTICAL SYSTEM OF BLACK-SOUNDING OPTOPHONE.

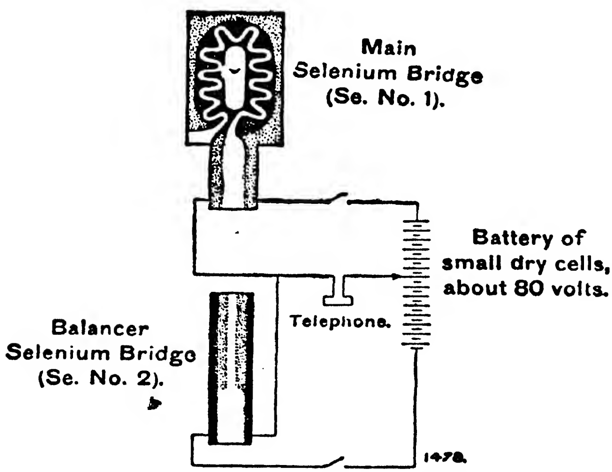

FIG. 17B.—SELENIUM CIRCUIT OF BLACK-SOUNDING OPTOPHONE.

And *Punch*, quoting a war description from a Scottish paper: "Not by straining his eyes to the utmost could he catch a sound," remarked, "He should have tried the new optophone attachment."

But the most important event was the demonstration given on August 30, at which Admiral Sir

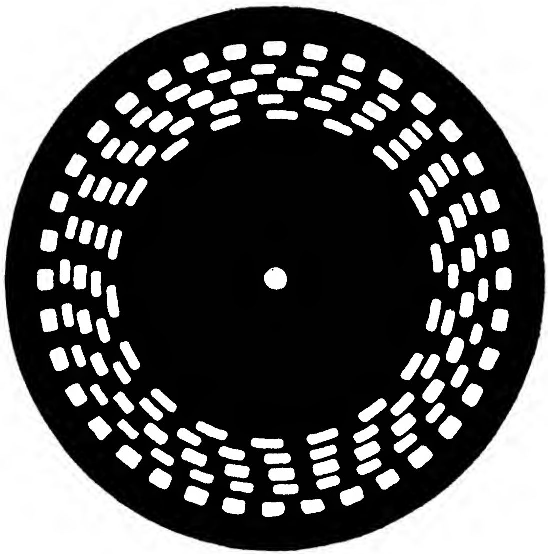

FIG. 17C.—OPTOPHONE DISC.

Reginald Bacon, then head of the Munitions Inventions Department, presided. Miss Jameson again read several lines faultlessly, and Sir Reginald Bacon was so impressed that he communicated with Messrs. Barr and Stroud, Ltd., a famous firm of instrument makers, advising them to take up the manufacture of the optophone.

That introduction proved of incalculable benefit

to the optophone. The wooden instrument on which Miss Jameson gave the first public reading exhibition (now in the Science Museum at South Kensington) was rather fragile and could only be transported from place to place with difficulty. It required the combination of fine adjustment with strength and durability such as would be supplied by the makers of Barr and Stroud's famous range-finders.

The manufacture of the optophone was a matter which could not be undertaken as an ordinary business enterprise. The number of blind people capable of benefiting by reading is limited. It is true that nearly half-a-million has been spent on providing them with Braille literature, and large annual sums are still expended on it, but it was not at all certain that a similar spirit of philanthropy would provide them with an expensive instrument for unlimited reading, and individuals capable of supplying themselves with it were few, and many of them were of an age unsuitable for acquiring a new accomplishment.

Nevertheless, Professor Archibald Barr, F.R.S., the head of the firm, spent many months of work and large sums in re-designing the instrument, making it compact and portable and "fool-proof," and providing it with some new contrivances and accessories which would render its use easy and safe even in the hands of an almost necessarily clumsy blind reader.

In order to make the instrument compact, it was decided to employ a curved glass plate on the book-rest, so that the optical reading arm (called the

"tracer") could be pivoted instead of running on a slide. The "tracer" was also moved down the page instead of making the page movable. Moreover, an automatic movement of the tracer along the line was substituted for the rack-and-pinion movement originally used by the Author. The motive power was a spring, controlled by an oil governor of extraordinary range and efficiency specially invented by Dr. Barr (Fig. 19, p. 67).

The accompanying illustrations show these features. But the most important modification, introduced by Drs. Barr and Stroud and the Author conjointly, was to make the black letters themselves produce the sound, instead of letting them blot it out. This was called the "black-sounding" system as distinguished from the "white-sounding" previously used. The effect was to reproduce the sounds as produced by the first reading optophone of 1913 (with large transparent letters).

On March 24, 1920, Dr. Barr brought the finished instrument before the Royal Philosophical Society of Glasgow. By an ingenious arrangement of reed sounders he was able to give his audience a very good idea of the sounds of various letters and actually made them "read by ear" the sentences: "Will Women Want to Vote? Wait and See."

In July of the same year, Dr. Barr had the honour of demonstrating the instrument personally to Their Majesties the King and Queen. This memorable event was reported by the *Daily Mail* on July 9, 1920:

"Their Majesties were able to test a new and wonderful device which enables the blind to read, or rather to hear, translated into musical notes, any printed matter. Hitherto reading for the blind has been possible only by means of the special Braille type. By this new invention, called the optophone—and Newington House is the first institution to acquire the apparatus—literature is translated into music.

"It is the invention of Dr. E. E. Fournier d'Albe, and has been modified and developed by Messrs. Barr and Stroud, of Glasgow, who make the giant heavy-artillery range-finders. In an ordinary telephone receiver is produced a series of musical notes, forming tunes representing the various letters as they are passed over by the instrument in traversing a line of printing.

"It renders all ordinary printed works, including typewritten matter, available to the blind, and it depends, not on touch, but on hearing, which is a peculiarly sensitive faculty with blinded persons. The music of the alphabet can be learned after a comparatively few lessons.

"The King and Queen listened to the melody provided by a chapter of the Bible being passed over the instrument. The sound is soft and pleasant, rather like the notes of a banjo floating across the water. 'It is wonderful,' was the King's comment."

Almost immediately after this auspicious day, the National Institute for the Blind decided to purchase an optophone from Messrs. Barr and Stroud (the price was then 100 guineas) and to make arrangements with the Author for daily lessons in optophone reading to be given to two selected pupils. These lessons began in October and continued for six months, with a view to a test at the end of the period.

On November 22, Messrs. Barr and Stroud presented one of the new "black-sounding" instruments to Miss Jameson, who thereupon set to work to reacquire her reading proficiency on a new system. As the system was still on its trial, whereas the "white-sounder" had already enabled her to read fifteen words per minute on the average, the Author decided to teach the N.I.B. pupils on the "white-sounding" system, particularly as the instrument as constructed can be worked on both systems (Fig. 20).

On January 5, 1921, a lecture was given by Dr. Barr (and read by Mr. Morrison, the London Director of the firm) before a joint meeting of the Physical and Optical Society at South Kensington. Some extracts from the *Morning Post* report are here appended :

"An astonishing demonstration of the advance of science was given last night in the Imperial College of Science, South Kensington. At a lecture given in connection with the exhibition of the Physical Society of London and the Optical Society, a blind girl read by telephone with perfect accuracy two lines of a book which had been selected at random. As I selected the page myself, and as Sir William Collins, a famous eye specialist, took an intimate interest in the experiment, I have no hesitation in saying that its result was beyond dispute. A distinguished doctor put the thing in a nutshell. His remark was, 'It beats Maskelyne and Cooke.'

"Leaving out all technical details, of advancing discovery and apparatus made to fit the discoveries, the main principle of the new system is this : By the use of selenium it is possible when tracing a delicate instrument over printed paper to translate the differ-

ences between white and black into musical notes, and the expert can transliterate each note into its appropriate letter, and spell out the words as they come out. The form of each letter causes it to sing its own little tune. They sound, at the first encounter, as similar as the chords blown on a mouth-organ, but after some practice the diligent student can distinguish between them. Five cardinal notes come into play, and are indicated to the careful ear—the lower G, and then the middle C, D, E, and G.

"Put a printed page on the machine, work it at the desired speed, and the blind reader can spell out the words—always supposing, of course, that he or she is good at spelling, for the optophone can do no more than represent the sound equivalent of the dark blotches, meaning the letters, it encounters on the body of the white paper.

"The value of this new invention to people deprived of sight is enormous. Work for which the nation can never be too grateful has been done by the Braille and Moon systems of providing perforated reading matter for the blind—but a Braille volume is twenty-five times the weight, and a Moon volume forty-five times the weight, of an ordinary printed book, and only one in ten thousand books is put into raised type for the finger reading of the blind.

"At the lecture the audience were invited to select a passage from a school primer, to see whether a blind person could read it. Being a journalist, with special reasons for satisfying myself as to the efficacy of the test, I volunteered. The offer was instantly accepted. I picked out, at random, the first line of page 85. The page was taken out, and put on the machine. A blind girl, Miss Mary Jameson, who has been studying the system for five weeks, put the telephone receivers to her ears, and read the words, with absolute accuracy, at about the rate at which a telegraphist

Fig. 29.—Miss Jameson at the Optophone.

would convey a message. The book was passed further down the bench, and then another line was read, this also without a fault.

" Mr. Francis Morrison, who read the lecture in the absence, through illness, of Emeritus Professor Archibald Barr, expressed the conviction that the reading of printed matter will be a real possibility for the blind in the future.

" At my request Sir William Collins expressed his opinion on the matter.

" ' I became interested in the optophone,' he said, ' from seeing one of the earlier models which Dr. Fournier d'Albe demonstrated to me. I have watched with interest its subsequent evolution, and I believe it has a future. It demands the prompt apprehension of minute differences of *motif*, and a certain degree of intelligence, patience, and aptitude. It should open up resources to some blind persons which have hitherto been denied them. Even with a little practice the *motif* of different letters can be differentiated.' "

This letter and demonstration seem to have provoked the anger and alarm of the hidden opponent who wielded Sir Arthur Pearson's name (he was too ill at the time to attend to anything, and died, in fact, shortly afterwards). The following extraordinary correspondence ensued :

" THE OPTOPHONE

January **6, 1921.**

" *To the Editor of the ' Daily Telegraph '*

" SIR,

" My attention has been drawn to a statement that has lately appeared in the public Press to the effect that there is an instrument named the ' Opto-

phone,' the invention of Dr. E. E. Fournier d'Albe, of London, by means of which the blind can 'read' ordinary print. It is claimed, moreover, that the Braille system will be superseded by this method, which is easy to learn. As this announcement is thoroughly misleading, and as, moreover, it may mislead hundreds of blind people, I trust you will find room in your valuable paper for this letter. The fact is that the National Institute for the Blind have been experimenting with the optophone for the last few months in order to ascertain whether an at present very intricate and expensive machine can in time be made of practical service to the blind. We hope soon to be able to report definitely as to the result of new investigations. Even if such a machine were ever to be made of practical value, to say that it would ever supersede the Braille method of reading is as true as to say that steam-rollers will ever supersede motor-cars, which is absurd.

"Yours faithfully,

"ARTHUR PEARSON."

National Institute for the Blind,
Great Portland Street, W.1.

The above letter also appeared in the *Star*, whereupon Miss Jameson wrote to the latter paper:

"A paragraph in your '"Star" Man's Diary' for Friday last has been read to me, in which Sir Arthur Pearson is represented as describing the optophone as incapable of 'being made of practical service to the blind.'

"I have been blind from birth. I learned Braille in my childhood, and I have recently taken part with credit in a public Braille reading-competition. I have also used the optophone, and I can therefore

speak with some practical knowledge of the two contrasted systems.

" With this knowledge I have no hesitation in saying that the optophone is of practical service to me. I have up to the present had just forty-eight hours' practice with the type of instrument I now use. In that time I have succeeded in reading an ordinary printed copy of some of Hans Andersen's Fairy Tales and also a Palmerston reader.

" I am hopeful that the optophone will prove of great service to all blind people. In the meantime I am glad to be able to testify to the use that it has been to me."

The " Impearsonator " felt he had gone too far, and hastened to modify his attitude. The *Star* of January 12 contained the following:

" Sir Arthur Pearson, President of the National Institute for the Blind, writes:

" ' Miss Jameson, the blind lady, whose letter about the Type-Reading Optophone appeared in your last night's issue, stated that I had said that the optophone was " incapable of being made of practical service to the blind."

" ' What I said was : " The fact is that the National Institute for the Blind have been experimenting with the optophone for the last few months in order to ascertain whether an at present very intricate and expensive machine can in time be made of practical service to the blind."

" ' Do not let me say anything which will lead the public to suppose that I am throwing cold water on this machine, for it is a masterpiece of ingenuity, and in these days of rapid advance in connection with scientific matters no one can tell where it may lead.

" 'At the same time, do not let us raise the hopes of the blind community by vague statements about blind people reading ordinary books.' "

The last Parthian shot concerning "vague statements about blind people reading ordinary books" was truly amazing. The statements were not vague, but perfectly definite. Blind people *can* read ordinary books. They *do* read ordinary books. Where is the vagueness? Or where is the exaggeration?

In any case, it was the last kick of the dying opposition, that opposition which came so perilously near to wrecking the optophone for an indefinite time.

Thereafter, one triumph succeeded another. On February 23, the Prince of Wales visited an exhibition at Olympia where the optophone was being shown, and took a short lesson in reading. In this connection, an amusing event occurred. Wishing to hear clearly, the Prince sent a message to the Guards band in the gallery to stop playing. Misinterpreting the message, the bandmaster finished the performance by striking up the National Anthem. The Prince is said to have smilingly remarked that he was a little premature!

In March a kinematograph film was prepared by the Gaumont Company to show the optophone in use at the National Institute for the Blind. That film had the honour of being shown to Their Majesties on the occasion of their visit to the Earl of Derby.

About the same time, successful attempts were made to amplify the optophone sounds so as to make

Fig. 21.

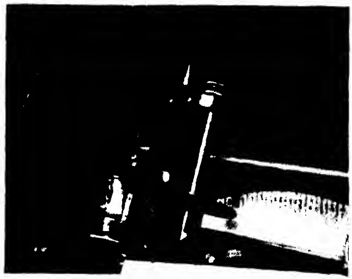

Fig. 22.

Fig. 23.

Fig. 24.

Fig. 25.

Fig. 26.

Fig. 21.—A BLIND MAN BEING TAUGHT TO READ "THE TIMES" ON THE OPTOPHONE.
Fig. 22. THE "TRACER" TRAVERSING THE LINE OF PRINT, SEEN FROM BELOW.
Fig. 23. INSERTING THE SELENIUM "EYE" INTO THE OPTOPHONE.
Fig. 24.—MISS GREEN READING A BOOK BY OPTOPHONE.
G. 25.—SAME.
G. 26.—MISS GREEN TYPING WHAT SHE HAS READ.

THE OPTOPHONE IN ACTION AT THE NATIONAL INSTITUTION FOR THE BLIND (*Gaumont Film*).

them heard by a large audience. The initiative in this matter was due to Mr. A. Campbell Swinton and Mr. C. P. MacCarthy. Miss Mabel Green, of the N.I.B., was able to read from the amplified sound, using the white-sounding system.

On April 6, 1921, Dr. Barr delivered a lecture on the optophone before the Royal Society of Arts, Mr. Campbell Swinton being in the chair. The lecture was followed by a demonstration of reading given by Miss Green, and by a discussion which marked a considerable advance in the public treatment of the optophone.

"The Chairman (Mr. Alan A. Campbell Swinton, F.R.S.), in opening the discussion, said the Author had mentioned the advantages and disadvantages of the optophone as compared with Braille and Moon type, and that reminded him of a story he had been told a few days ago about an elderly gentleman who was losing his sight and therefore was learning to read Braille. He said the great advantage of Braille was that in cold weather one could read in bed and still keep one's hands under the bedclothes. He was afraid the optophone was not perhaps adapted for that! He was also reminded by the Author's remarks of an interview he had some years ago with Prof. Graham Bell, the inventor of the telephone. Prof. Bell said to him on that occasion: 'You know people think that I am an electrician, but I am not. On the other hand, one of my friends said I could not be an electrician, because if I had been I should have known beforehand that my telephone could not work.' He thought perhaps that remark had some bearing upon Dr. Fournier d'Albe's wonderful inven-

tion, because he did not think any electrician would have believed it possible to make the optophone work —certainly not to make it work in the wonderful way that had been achieved by the Author.

"Mr. Henry Stainsby (Secretary-General of the National Institute for the Blind) said that since the year 1914 he had been very much interested in the optophone. It was in that year, just before the outbreak of the war, that Dr. Fournier d'Albe gave an exhibition of the optophone at a very important International Conference on the blind, which was held at the Church House, Westminster. As the Author said, the subject remained in abeyance for a long period, in consequence of the war, but had now been revived, and the Institute with which he was connected had taken an active part in testing the apparatus and in affording facilities for instruction in its use. At the request of the Inventions and Research Committee of the Institute he had undertaken to make the tests, but they were not yet completed, so he was not in a position to give the results of them, and the remarks he was about to make were, therefore, personal and not official. He had come to the conclusion that the optophone had not yet had a fair test. The human material that had been used had not been of the right kind. People were taught to read in the ordinary way very early in life, and he was convinced that if the optophone was to be properly tested, the tests should be carried out in a school amongst young children, and should extend over a long period. If that plan was adopted he was very much inclined to think that the results would surpass general expectations. The Author had mentioned the Braille and Moon type, in both of which types the National Institute for the Blind published the bulk of the literature issued for the blind in the whole world. The Moon type did not occupy quite so

much space as the Author thought; indeed, not quite half as much; nevertheless, both the Braille and the Moon types were extremely bulky. The great advantage of the optophone was that it put the literature of the whole world at the command of the blind, whereas tactile print gave them a very limited field indeed. Therefore, if the optophone proved a success, as everyone sincerely hoped it would, a great deal more reading matter would be put at the command of the blind than was at present available to them.

"The Hon. Sir Charles A. Parsons, K.C.B., F.R.S., in seconding the vote of thanks, said the optophone embodied more physical inventions and properties of matter than almost any instrument he had ever seen. It provided a beautiful means of linking the musical gamut with the altitude of the letters. A musician could, by reading music, appreciate its beauty and harmony from very long experience beginning at an early age, and in the optophone there was the transfer of letters into the altitude of the 'doh, ray, me, soh' gamut. He remembered once hearing that some Japanese were buried in a graveyard at Newcastle-on-Tyne, and they had a tombstone with an inscription in Japanese letters, and two pitmen happened to go by it one day. One asked the other if he could read it, and he replied: 'No, but if I had my fiddle I might play it!' The optophone contained some most beautiful mechanical devices. The whole mechanism, in fact, was perfectly wonderful, and the governor was quite original. He was sure everyone present was very much indebted to the Author for explaining the instrument so very lucidly. He thought the principles involved in it were probably capable of very great enlargement and elaboration in the future, and it might be made to reproduce music in the same way as it read printing.

"Mr. Archibald Barr, LL.D., D.Sc., in reply, said it had been a great pleasure to him to have interested those present in the optophone, which he thought had considerable possibilities before it. Dr. Fournier d'Albe had referred to the perforations on the disc. That disc was made by the very simple process of drawing a picture of the disc, photographing it upon the metal, and etching it through. In that way it had been possible to make the disc exceedingly true, of a very thin light material, and at a reasonable cost. Dr. Fournier d'Albe had also said that Miss Jameson had been able to read French by the optophone, and he might mention that Miss Jameson told him that she thought French characters were more easy to read than English, on account of the accents. She found the accents an advantage rather than a disadvantage. With regard to Miss Green's demonstration, the speed at which she had read on the present occasion must not be taken as her best speed, partly on account of the circumstances and also for the reason that whereas with Braille one could speak and feel at the same time, one could hardly listen and speak at the same time, as was necessary in reading aloud with the optophone. In connection with the remarks Sir Charles Parsons had made about the automatic gear controlled by a governor, he might say that the instrument had a little spring which had very considerable difference of driving power, and the tracer had very considerable weight. The arrangement was such, however, that when the spring was strong the tracer had to be raised and when the spring became weaker towards the end the tracer helped it. The result was that a uniform torque was obtained, which caused the instrument to be driven at a uniform speed."

On April 14, Miss Jameson gave a demonstration

in Paris, when she performed the seemingly wonderful feat of reading French. It so happened that the chief French periodical published in the interests of the blind, *L'Ami des Aveugles*, had published (February 1921) a criticism of the optophone on the ground that an automatic machine could never be used for the "infinite variety" of type to be found in books. The result of Miss Jameson's visit was a cordial *amende* in the April number. It said:

"Endowed with a bright intelligence and charming grace, Miss Jameson victoriously replied to all our

FIG. 27.

objections. She easily read with the optophone a line chosen at random in the *Ami des Aveugles* which we gave her to read without preparation."

When the official report of the N.I.B. appeared, it was found that the main question at issue—can the blind read by ear?—was at length officially answered in the affirmative, while the question of speed was left open. The salient passages of Mr. Stainsby's report are given below:

"I have tested Miss Green's reading on the optophone on seven different occasions, each test being of thirty minutes' duration and on 'unseen matter,'

"(1) Extract from *Heroes of the Darkness*, eighty-five words in thirty minutes, say three words per minute.

"(2) Extract from leading article of *Daily Telegraph*, sixty words in thirty minutes—two words per minute.

"(3) Extract from *Optimism*:

"Test (*a*) Eighty-nine words in thirty minutes, say three words per minute.

"Test (*b*) Seventy-eight words in thirty minutes, say two-and-a-half words per minute.

"Test (*c*) Sixty-four words in thirty minutes, say two words per minute.

"(4) Extract from *The World I Live in*, sixty-five words in thirty minutes, say two words per minute.

"(5) Extract from *Pier's Plowman Histories*, Junior, Book II, one hundred and nineteen words in thirty minutes, say four words per minute.

"It will thus be seen that the average speed is under three words per minute. Although slow the reading was accurate, very few words being unread or miscalled. Short and easy words of frequent recurrence were read with comparative ease, the reader evidently taking the word as a whole without analysing into letters. This is borne out by the last test, which was from a junior school book in everyday English. Long and uncommon words, particularly those containing little used letters as 'z,' caused much delay and consequently brought down the averages. Towards the close of a test the reading became slower, demonstrating the fact that until it becomes mechanical it will be tiring. This was obvious in the last test, when Miss Green read the first twenty-four words in four minutes, or six words

per minute. This condition exists in a very marked degree in tactile reading, learners always being recommended to take their lessons in small 'doses.'

"Notwithstanding this, I am assured by Miss Green that she does not experience any tired feeling. Further, she assures me that the process of listening neither prevents her from grasping the full import of what she has read nor detracts from the enjoyment which she ordinarily gets out of reading.

"Miss Green manipulated the instrument quite unaided, and occupied less than two minutes in placing her book in it ready for reading.

"I am informed by Mr. Emblen, the other optophone student, that my tests, while perfectly fair, do not do justice to Miss Green. This is doubtless due to the fact that examinations of all kinds rarely show the examinee in the best light.

"In preparing this report I have had two main issues in mind, all others being in my judgment quite subordinate to these two. The first is, can blind people read ordinary ink-print matter? The reply to this is emphatically yes. The second is, can they read at a speed which would make it worth their while to adopt the optophone as a reading instrument? On this point I have already shown that speed is slow, but as a set-off against this it should be borne in mind, first, that no one has had adequate practice upon it, and secondly, that the right type of learner has not been tested. After mature consideration I have come to the conclusion that tests should be made on young children in a school for the blind, and that the same facilities should be afforded them as for tactile reading. In the latter this period extends over a number of years, and fluency is only attained after long practice. While I am inclined to think that tactile reading will be more easily acquired than reading by means of the optophone,

it must be borne in mind that the literature available through the former is relatively small, but through the latter world-wide and unlimited."

The examination on which this report was based had been conducted by Mr. Stainsby with the most scrupulous fairness. It was published in *St. Dunstan's Magazine* and subsequently issued in pamphlet form.

Miss Green's practice had extended over one hundred and twenty hours, which should have given her a speed of six words a minute, it having been found that the number of hours divided by twenty gives the approximate speed in words per minute. As a matter of fact, she often attained speeds of fifteen or even twenty words per minute, but important examinations are very special occasions!

The main question being now decided in favour of the optophone, it remained to prove the speed of which it was capable. This has since been done by Miss Jameson, in a manner far beyond the inventor's most sanguine expectations.

In July 1922, Miss Jameson attended the *Congrès National pour l'Amélioration du Sort des Aveugles* in Paris, and presented a report on the optophone, written in excellent French, which was well received and subsequently published in full.

On April 14, 1923, she visited the War Invalids' Exhibition at Brussels, and gave test readings in French and English in the presence of the Queen of the Belgians, who is herself the daughter of a Royal oculist.

Finally, in June 1923, she gave a demonstration at an exhibition organised by the National Institute for the Blind, where she read at the rate of sixty words a minute, to the amazement of the officials present, some of whom may have been among the former opponents of the optophone.

Even that record was surpassed at the meeting of the British Association in Liverpool, where on one occasion her speed attained eighty words a minute. There seems no reason why she should not eventually attain the speed of eye-reading, which is about two hundred words a minute. (See Fig. 29, p. 68.)

She says: "I read without spelling the words. I read words and sometimes whole phrases as such. The first book I read from cover to cover was Anthony Trollope's *The Warden*, a volume of the Everyman Series. The second was Hawthorne's *Scarlet Letter.* I also borrowed Knowlson's *Art of Thinking* from the Croydon Library and read it right through. It gave me a great deal of pleasure."

In the United States the optophone was first introduced by Mrs. Edward C. Bodman, of New York, who took a special interest in blinded soldiers. At least one pupil has learnt to read there, and given satisfactory demonstrations, but there are as yet no teachers available.

And there we must leave the optophone for the present. It forms a romantic chapter in the history of the applications of science to the welfare of humanity. Scientifically speaking, the problem of

reading for the blind is completely and finally solved. The constructional problem is also solved in a most satisfactory way. It remains to reduce the cost of production in order to bring it within the reach—not of the average blind, for that is impossible—but of those organisations and institutions which are founded to supply the needs of the blind. Above all, there must be an organisation for training and supplying teachers. But those matters are for the philanthropists and public bodies; and are outside the scope of a scientific work.

CHAPTER IX

CONVEYING SPEECH ALONG A BEAM OF LIGHT

When, forty-three years ago, Graham Bell, the inventor of the telephone, transmitted speech for three hundred yards along a beam of light, a new era of human communication seemed about to come upon the world. The feat was worthy of a man of consummate genius, whose ability seems never to have been properly appreciated.

The method which he used to impress speech vibrations upon a beam of light was highly ingenious and extremely simple. He spoke into a funnel closed by means of a thin glass diaphragm coated with silver. In the course of its vibrations, the flat diaphragm became alternately convex and concave. If a beam of parallel light was thrown on the diaphragm, it was only transmitted in its entirety to a distance when the mirror was flat. Any convexity or concavity reduced the amount of light received at the distant station. Speech thus produced an alternation of light and darkness, and this alternation was faithfully reproduced by selenium at the receiving end. Bell used a parabolic mirror and a cylindrical selenium cell made of circular brass plates insulated with

mica. He also experimented with a number of other receivers such as lampblack and other forms of carbon. He called his apparatus a "photophone" (light-sounder), a word which is very appropriate and easily distinguished from the optophone or "sight-sounder."

When, in the beginning of the present century, Simon and Duddell invented the Speaking Arc, an opportunity was given for a new departure in the photo-transmission of speech. They put a transformer in the circuit of an arc lamp and a telephone transmitter in the secondary circuit of the transformer. On speaking into the transmitter, slight fluctuations were imposed upon the arc, which "spoke" the words with the speaker. The fluctuations thus heard were accompanied by fluctuations of the arc-light, and these, when received upon a selenium cell at a distance, reproduced the original speech.

An experiment for demonstrating this effect is shown in Fig. 30. Acetylene is admitted through the tube A into a chamber separated from the mouthpiece M by a thin diaphragm of rubber or goldbeater's skin. On speaking into the mouthpiece the flame fluctuates, and intermittent light falls on the selenium cell B. On connecting a battery and telephone receiver to the terminals C D the speech may be heard in the telephone (which may, of course, be at the end of miles of telephone wire). The light can be transmitted by a concave mirror or lens over a considerable distance, but the range is limited

by the comparatively small intrinsic brilliancy of acetylene.

Ernst Ruhmer, the German inventor who died just before the war, succeeded by means of the speaking arc in transmitting speech over a distance of six miles.

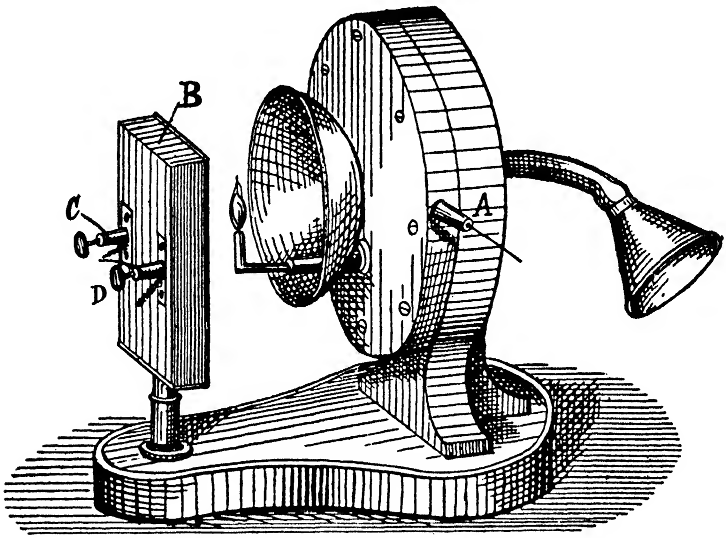

FIG. 30.—ACETYLENE PHOTOPHONE.

His experiments were conducted on the " Wannsee " near Berlin.

During the war the Author developed a method of transmitting Morse signals invisibly along a searchlight beam, but the most useful work was accomplished by Professor A. O. Rankine, of South Kensington, who, in conjunction with Sir Wm. H. Bragg, devised an entirely new method of impressing speech variations upon a beam of light. It was done

by utilising the vibrations of a mirror attached to the needle-clip of a sound-box as used in the gramophone. The needle vibrates over an angle of about a quarter of a degree, and it was necessary to find a way of concentrating an intense beam of light on the mirror and making its movement produce the necessary complete fluctuations. To solve this problem, Professor Rankine conceived the idea of transmitting an arc-light through a lens pasted over with a number of parallel strips of paper, forming a sort of grating. The small mirror was chosen of a focal length equal to half the distance between itself and the grating, so that an image of the grating was formed at the same distance from the mirror. This image fell upon a similar grating stuck on a lens of twice the focal length of the mirror, so that it could act as a search-light projector. In a state of rest, the image coincided with the second grating, and light was transmitted through half the surface of the second lens. But when speech entered the sound-box, the vibrations of the mirror led to a rapid series of extinctions of the light, by the dark portions of the image coinciding with the transmitting portions of the second grid. The light was thus made intermittent in accordance with the sound vibrations, and could be received on a selenium cell, and reconverted into sound.

On this principle, with some improvements in detail, Rankine constructed a new photophone which was extensively tested during the war in the Firth of Forth. Speech was transmitted in both directions

between Hawkcraig and the island called Inchcolm, using the Author's selenium cells ("B" type) at both ends. A grid-photophone of this kind was shown in action at the British Association meeting at Liverpool in September 1923, the stations being at St. George's Hall and the Technical School respectively.

The photophone works best with the aid of sunlight, which has a greater intrinsic brilliancy than any terrestrial source. Its utility in desert and tropical countries where perpetual sunshine can be counted upon is obvious, and so are its advantages over wireless telephony so long as the latter cannot be made secret.

Professor Rankine has lately constructed a photophonic microphone for use in wireless telephony. It has certain advantages over the carbon microphone which he explained as follows in a recent interview:

"In the more recent developments of telephony, especially wireless telephony, and broadcasting in particular, the original sound energy has perforce to undergo in the process of transmission so many transformations and amplifications, each with its own liability to introduce distortion, that the accumulated effect on the final reproduction may reduce it to incomprehensibility. If, in addition, as is now a common practice, loud speakers with their admitted imperfections, are employed, distortion is still further enhanced.

"It is evident that, in these circumstances, it is not

safe to begin with anything but the best. In a broadcasting station expense and complication of apparatus are relatively unimportant matters; the chief thing is to put into the transmitting valve as accurate as possible an electric copy of the sounds it is desired to broadcast, so that something more than occasional recognition of words may survive the subsequent series of distortions.

"It is in this connection that the carbon microphone is finding its rivals, and, in some broadcasting stations, being abandoned in favour of them. I cannot do more than mention some of the various possible substitutes, the function of which, as we have seen, is to control accurately electrical power by means of sound vibrations. Curiously enough, one method which is attracting considerable attention is a reversion to the principle of Graham Bell's original transmitter, which used to serve the double purpose of transmitting and receiving. In this the electric currents are produced by the inductive action of the magnetic material of the diaphragm vibrating close to the coils surrounding the fixed magnet. Then there is the photophone, in which the sound vibrations control, first of all, a beam of light, which, in turn, through the agency of a selenium cell, operates an electric current.

"In both of these the fluctuating currents are feeble compared with those obtainable by means of the carbon microphone, and have to be amplified by thermionic valves before application to the transmitting valve, but the results are of very distinctly superior quality. The photophone microphone, if I may so call it, is actually in use at the Manchester station."

It may be confidently anticipated that a simple photophone transmitter of the Rankine type, easily

installed at any stations within sight of each other, and so closely directed that the messages can be received at one window of a house and at none of the others, will soon form one of the ordinary means of telephonic communication.

CHAPTER X

KINEMATOGRAMS OF THE VOICE: THE TALKING FILM

The conversion of light into sound and its reconversion into light immediately suggests the possibility of reversing the process, and beginning and ending it with sound. The recording and reproduction of sound are, of course, as old as Edison's phonograph, which he invented in 1874. But the various efforts hitherto made to reproduce a sound simultaneously with the visible action accompanying it have not succeeded satisfactorily on any method involving the phonograph or gramophone. The reason is not far to seek. The Kinematograph works with a continuous film usually moved at a certain rate by hand. The gramophone works mechanically, and if the sound is to accompany the action there must be perfect synchronism between the two mechanisms. It has been found impossible to secure this, although some very wonderful results were achieved, notably in the "Kinetophone" and the "Kine-Opera" shown in London some fifteen years ago.

In 1908, Ernst Ruhmer invented the "Photographophone," which recorded the sounds of the speaking arc on a moving film in the shape of a

"ladder" closely resembling a spectrum traversed by Fraunhofer lines (see Fig. 31, p. 93). On passing this record over a slit traversed by a beam of light and provided with a selenium cell, Ruhmer was able to hear the original sound accurately reproduced, through no other mechanism than that of light and the telephone receiver.

Many other attempts in the same direction followed this first effort. Grindell Matthews in England and Professor Berglund in Sweden attained good results, the former adopting the ingenious device of photographing the sound record on the margin of the film itself, so that a perfect synchronism was necessarily maintained. Strange to say, both these pioneers used a sort of wave-record, the amplitude of the wave not being shown by the intensity of the photographic blackening but by the extension of the wave at right angles to the margin of the film. One cannot help thinking that any success obtained in that direction was a more or less secondary effect.

A first-class inventor who has lately taken up the same problem is an American, Mr. Lee de Forest, who invented the triode valve or *Audion* in 1912, thereby inaugurating the new wireless era which replaced the era of crystals and electrolytic detectors.

Instead of using a speaking arc, Mr. de Forest uses a small cathode ray tube which he calls a "Photion."

A vivid account of the new process was given in an interview with the inventor recently published in

the *Wireless Review*, from which we quote the following extract:

"Perhaps you have seen lately some of the neon-filled glow lamps which are being used to attract attention in stores and shop windows. A tube of bent glass, often shaped into words or letters, contains a little of this neon gas, about one-thousandth of 1 per cent. of which is contained in ordinary air. When a high-frequency electric current is sent through this neon-filled tube, the gas glows with a soft reddish light which is pleasant and attractive. The photion works on much the same principle. Of course, the gas in it is not neon, and the glow is violet, not red. But it, too, is a gas glow excited by an electric current.

"If you watch carefully the glow of a photion in operation you may be able to see that the light is not absolutely constant. It flickers a little. Pulses of greater brightness alternate with brief instants when the glow is a trifle dimmer. This means that the photion is translating sound into light. The rapid flickers and pulses which you see mean that you are literally seeing speech.

"The photion tube is excited by a high-frequency electric current, modulated by the voice in exactly the same way as in a small radio-telephone transmitter. This part of the apparatus is in fact identical with the radiophone transmitter.

"In the electric circuit which operates the photion, and which causes it to glow, we insert a highly special substitute for the microphone and one or more vacuum tubes as amplifiers. This receiver picks up sound waves and converts them into pulses of electricity. The electric pulses, after being amplified sufficiently, control the radiophone which is exciting the glowing photion and affect its light. The flickerings of this light, its rapid brightenings and dimmings,

correspond exactly to the waves of sound which enter the microphone.

"This shows you how the phonofilm process transforms sound into light; but how does it photograph them, how do we secure a permanent record of them on the motion-picture film?

"This is how. The glowing photion is in a little chamber by itself inside the camera, and this chamber is light-tight except for one tiny slit only one millimetre long and a fortieth of a millimetre wide. The moving film on which the motion picture is being taken runs past the photion chamber in such a position that the edge of the film passes just under this slit. The light from the photion streams through the slit and is photographed on the film, making the strip of tiny hair-like lines already described; a darker line for each instant when the photion is brighter, a less dense line when the light of the photion is a little more dim.

"This little ladder of lighter and darker lines is our photograph of sound, our answer to the problem of recording successfully both the sight and the sound. The width of the sound photographs is always the same. The *intensity* of the light, and that alone, is varied by the sound. This feature distinguishes a phonofilm from all other methods, and permits a more faithful reproduction of every light and shade of sound than is otherwise possible. And by this photion or phonofilm method, it is seen, there is complete absence of any mechanical moving parts, nothing in the entire system up to the final diaphragm of the loud-speaker which can introduce a natural period of vibration of its own, tending to distort the original sound, in recording or in reproduction. So far as the taking of the moving picture is concerned, this is the whole of the story.

"But how is one to get this back into real sound

again? How is the sound record on the film to be reproduced when the motion picture is run off in the theatre?

"Consider, first, what the problem is. The taking of the talking motion picture involved two successive conversions of one kind of vibration into another kind. First the waves of sound were converted into electric waves by the microphone. Next the electric waves were converted into light by the photion. Now we must do these same two things in reverse order. On the finished film is our little ladder of darker and lighter lines. A ray of light can be made to shine through this ladder, and the strength of the light that gets through will correspond to the lines on the ladder. As each dark line passes across, the light transmitted will be momentarily dimmer. This gives us, to start with, what we finished with when the moving picture was taken, namely, a light which flickers in exact correspondence with the waves of sound. The problem is to convert these flickers back again into real sound."

Mr. de Forest prefers to use photo-electric cells for the reconversion of the record into sound. It is, of course, one of the possible ways of doing it, though the Author is inclined to think that it is not the most effective.

Professor Rankine has also succeeded in reproducing speech from a film on which he took records of words as produced by his grid photophone. Three of these beautiful records, those of the words "Beet," "This," and "Man," are reproduced in Fig. 31, p. 93.

It will be noticed how the "ladders" change in character along the strips. The closer texture of the

third record is due to the strength of the first overtone contained in the vocal a.

Although the problem of the Talking Film is thus practically solved, kinema managers are doubtful of its popularity. They say that kinema acting is independent of sound. It is an art in itself, and would not be benefited by introducing sounds which are not required. It would also reduce the number of good kinema artistes considerably if only those with good voice production (and a good accent !) could be employed. And lastly, the kinema film would no longer be the international thing it is now, easily adapted to any country by putting in the "legends" in the language of the country where it is shown.

The utility and the promise of the Moon-element are by no means fully revealed as yet. It is unsurpassed in its function of producing electric currents from light. It is the supreme bridge between two of the most vital forms of energy. It enables us to convey our thoughts and our will along the highway of the ether of space. The coming generation will see signs and wonders which at present we can only surmise, but which will eclipse the marvellous results already achieved with the help of the Wonderful Element.

APPENDIX

ON THE USE OF SELENIUM IN STAR TRANSITS

For use in connection with the transit telescope belonging to Birmingham University a special selenium bridge was prepared consisting of a narrow line of sensitised selenium on porcelain, mounted on ebonite so as to fit into the eyepiece end of the telescope. The line was 4 mm. long and 0·5 mm. wide, and it was placed 3 mm. behind the middle crosswire of the instrument, and parallel to the crosswire. The focal length of the objective being 30 inches, the transit of an equatorial star across the selenium gap occupied 9·0 seconds. The aperture used was 2 inches. The selenium bridge, whose resistance was about 20 megohms, was inserted in an accumulator circuit giving 50 volts, and containing one coil of the Thomson differential galvanometer used before. A compensating current was sent through the other coil. The magnetic field was adjusted so that the galvanometer gave a deflection of 320 divs. per micro-ampère. The swings were damped, when necessary, by means of an adjustable resistance in the compensating circuit.

The results are given in the following table. The smaller deflections were practically aperiodic. In the case of the larger ones (Spica and Arcturus) the aperiodicity was secured by artificial damping. The efficiencies obtained were so much in excess of those obtained before that they are best expressed in ohms per lumen instead of microhms per lumen. The faintest illumination of the objective lens was 0·0078 micro-lux, but as the light

RESULTS OF TRANSIT OBSERVATIONS, BIRMINGHAM, MAY 23, 24, AND 26, 1913

Constellation	VIRGO				BOOTES		
Star	α (Spica)	ζ	m	ι	ι	η	α (Arcturus)
Right Ascension	13h. 20m.	13h. 30m.	13h. 37m.	13h. 57m.	13h. 43m.	13h. 51m.	14h. 12m.
Declination	10°42′S.	0°9′S.	8°15′S.	1°59′N.	17°54′N.	18°51′N.	19°39′N.
Illumination of objective, microlux	0·36	0·048	0·0078	0·020	0·017	0·084	0·78
Illumination of Se, microlux	22,000	3,000	485	1,240	1,060	5,200	48,000
Light received, 10^{-12} lumen	730	97	15·8	40·4	34·4	170	1,580
Galvanometer deflection, mm.	12[1]	5	2[2]	3	3[1]	5	18[2]
Current, microamps	0·037	0·0156	0·0062	0·0094	0·0094	0·0156	0·05
Diff. conductivity, 10^{-12} mhos.	740	310	124	188	188	310	1,120
Galvanometric efficiency, mhos per lumen	1·01	3·2	7·8	4·6	5·5	1·82	0·71
$\sqrt{\text{Illumination}}$	0·6	0·219	0·088	0·141	0·13	0·29	0·88
Diff. Cond. / $\sqrt{\text{Illumination of objective}}$	1,230	1,410	1,410	1,330	1,450	1,170	1,260

[1] Three transits.

[2] Two transits.

is concentrated upon a disc 62,000 times smaller in area than the objective, the faintest actual illumination of the selenium was as high as 485 micro-lux. As the Se bridge used showed very little inertia, it may be safely assumed that the deflections observed are a measure of the " final " deflection. In any case, the original resist-

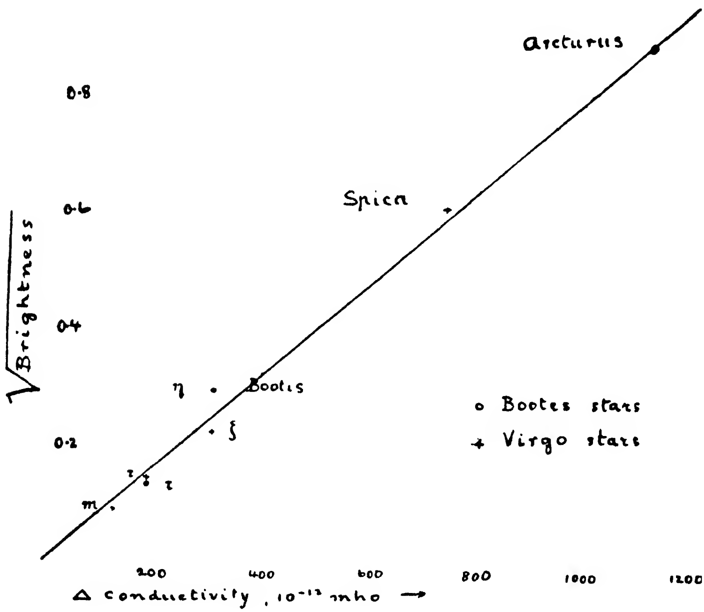

FIG. 32.—SELENIUM MEASUREMENTS OF STARS.

ance was recovered within a few seconds after the transit had taken place.

The above diagram shows the relation between the difference of conductivity and the square root of the illumination. It is seen that the relation is a linear one, thus confirming the results obtained with small artificial illuminations.

It may be added that it was found possible to make the

light reflected by the galvanometer mirror impinge upon a second Se bridge, and so reduce the resistance of the latter sufficiently to work a relay. In this way, automatic records could be obtained of deflections of not less than 5 mm. A Nernst lamp was used in this case.

E. E. FOURNIER D'ALBE.

INDEX

Printed in Great Britain by Hazell, Watson & Viney, Ld., London and Aylesbury.

THE HEAVENS. By J. H. FABRE, Author of "The Wonders of Instinct," etc. Translated by E. E. Fournier d'Albe. Demy 8vo, cloth. 15*s*. net.

This book teaches astronomy in a manner characteristic of the great naturalist. It is notoriously difficult to render the movements of the stars and planets intelligible to the untrained mind, but Fabre takes nothing for granted. He builds his teaching entirely on common everyday observation and leads his pupils by easy stages to the greatest heights of the Sublime Science.

THE WONDER BOOK OF PLANT LIFE. By J. H. FABRE, Author of "The Wonders of Instinct," etc. Translated by Bernard Miall. Illustrated. Demy 8vo, cloth. 15*s*. net.

This volume shows us yet another aspect of the "incomparable observer"—to quote no less an authority than Darwin. Fabre the botanist is no less delightful than Fabre the entomologist, and the tens of thousands of readers who lament that his great masterpiece has not been published in its entirety will find that there is still a treat in store for them.